Improvement of Subtropical Fruit Crops

Contents

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IMPROVEMENT OF SUBTROPICAL FRUIT CROPS: CITRUS

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MORE than half of the 13 fruit crops known to have been cultivated longer than 4,000 years, according to the researches of De Candolle (*7*)[1], are tropical and subtropical fruits—mango, olive, fig, date, banana, jujube, and pomegranate. The citrus fruits as a group, the lychee, and the persimmon have been cultivated for thousands of years in the Orient; the avocado and papaya were important food crops in the American Tropics and subtropics long before the discovery of the New World. Other types, such as the pineapple, granadilla, cherimoya, jaboticaba, etc., are of more recent introduction, and some of these have not received the attention of the plant breeder to any appreciable extent.

Through the centuries preceding recorded history and up to recent times, progress in the improvement of most subtropical fruits was accomplished by the trial-error method, which is crude and usually expensive if measured by modern standards. With the general acceptance of the Mendelian principles of heredity—unit characters, dominance, and segregation—early in the twentieth century a starting point was provided for the development of a truly modern science of genetics.

In this article it is the purpose to consider how subtropical citrus fruit crops have been improved, are now being improved, or are likely to be improved by scientific breeding. Each of the more important crops will be considered more or less in detail. Before proceeding to these considerations, however, it is desirable to define the province of subtropical fruit culture and to take a glance at the economic importance of the subtropical fruit industry.

The region where subtropical fruits are produced, as the name indicates, is between the true Tropics, where frost never occurs, and the temperate region, where normally the temperature often falls below freezing and stays below for a considerable part of the winter season. In this intermediate region the temperature occasionally goes below freezing but not as a rule below 25° F., so that when necessary the trees can be economically protected by artificial means. Because of the influence of large bodies of water, the protection of mountain ranges, or planting where the topography gives good air drainage, this type of region may be extended as "islands" considerably beyond the usual subtropical region.

The types of fruit crops grown merge into those of the true Tropics—citrus, avocado, mango, etc.—and no hard and fast division can be

[1] Italic numbers in parentheses refer to Literature Cited, p. 806.

drawn on the basis of fruit types except that forms possessing resistance to low temperature are of major importance in the subtropics. Diverse types are cultivated, of which the familiar citrus fruits are among the most outstanding, followed by the pineapple, fig, olive, avocado, date, persimmon, mango, papaya, guava, pomegranate, lychee, granadilla, cherimoya, loquat, jujube, and other minor types.

In the United States some of the crops, notably citrus and avocado, have become staple dessert and salad fruits. Others, notably the date and the fig, are used primarily as confections. The olive is used in preserved form or for oil. Some of these fruits were recognized as important sources of indispensable vitamins even before the true function of these chemical regulators was fully understood. Limes, for instance, have long been included by the British as a regular part of the diet of seamen as a preventive of scurvy. During the recent Ethiopian campaign, the entire Italian export crop of lemons was reserved for the army of invasion, and it is reported that deficiency diseases were at a minimum. Besides the citrus group, pineapples, papayas, dates, avocados, mangoes, and other subtropical fruits are known to be unusually high in vitamins.

Some of these fruits, for example the mango and the papaya, are extensively cultivated but primarily for local consumption. Higgins and Holt (*30, p. 17*) remark: "Excepting the banana, there is no fruit grown in the Hawaiian Islands that means more to the people of this Territory than the papaya, if measured in terms of the comfort and enjoyment furnished the people." This applies to the papaya in other tropical countries as well; to the avocado in Central America and the West Indies; and to the mango in India, southeastern Asia, Malaya, Puerto Rico, and the West Indies in general.

OUTSTANDING *in the story of citrus fruit improvement was the work of A. D. Shamel, of the United States Department of Agriculture, and his coworkers, in studying bud mutations. In the past 18 years, probably 10 million buds of superior strains of the Washington Navel orange, the Valencia orange, the Marsh grapefruit, the Eureka lemon, the Lisbon lemon, and miscellaneous citrus varieties have been sold to California growers alone as a result of this work. Two special strains produced fairly recently—the Robertson Navel orange and the Dawn grapefruit—are now being widely distributed and seem to have great promise. In addition, the intensive study of bud mutations, backed by careful statistics, was important in teaching growers to keep a close watch for branches mutating toward poor types, so that they could be eliminated from the orchard.*

The subtropical fruit production regions in the continental United States are indicated in figure 1. The annual farm value (1934–35) of the chief subtropical fruit crops grown in the United States for

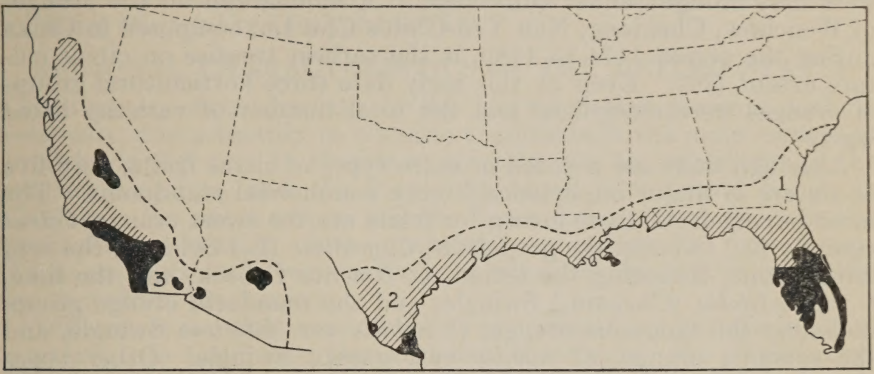

Figure 1.—Citrus-producing areas of the United States. Solid black denotes areas of commercial production of sweet and tangerine oranges, grapefruit, or acid citrus fruits (lemons or limes). Shading denotes areas producing satsuma oranges or minor quantities of other citrus fruits. The dotted boundary lines indicate the approximate northern limits of the three subtropical crop regions: (1) Southeastern humid, (2) central irrigated, and (3) southwestern irrigated.

which figures are available—citrus, fig, olive, avocado, and date—amounts to approximately $140,000,000, distributed as follows: Citrus fruits, $135,000,000; fig, $1,706,000; olive, $1,260,000; avocado, $959,000; date, $390,000.

The distribution of the total return for citrus fruits in the United States in 1934 is given in table 1.

TABLE 1.—*Citrus production in the United States 1934*

[From the United States Department of Agriculture, Agricultural Statistics, 1936]

Fruit	State	Total production	Price per box	Total value
		Boxes	*Dollars*	*Dollars*
Oranges	California	41, 565, 000	1. 80	74, 817, 000
	Florida	15, 500, 000	1. 55	24, 025, 000
	Texas	595, 000	1. 05	624, 750
	Arizona	170, 000	1. 50	255, 000
	Alabama	140, 000	1. 15	161, 000
	Louisiana	293, 000	1. 25	366, 250
	Mississippi	88, 000	1. 30	114, 400
Total or average		58, 351, 000	1. 72	100, 363, 400
Grapefruit	Florida	12, 500, 000	. 91	11, 375, 000
	California	1, 788, 000	1. 10	1, 966, 800
	Texas	2, 720, 000	. 85	2, 312, 000
	Arizona	1, 240, 000	. 85	1, 054, 000
Total or average		18, 248, 000	. 92	16, 707, 800
Lemons	California	7, 500, 000	2. 30	17, 250, 000
Limes	Florida	8, 000	3. 50	28, 000
Total				134, 349, 200

EARLY HISTORY OF CITRUS FRUITS

The citrus fruits as a class are native to southeastern Asia—eastern India, Indo-China, southern China, the Philippines—and here they were first brought under cultivation. A monograph on the oranges of Wenchow, Chekiang, Nan Yen-Chih's Chu Lu, composed in China during the period 1174 to 1189, is the earliest treatise on citrus culture extant (*26*). Even at this early date three horticultural groups of oranges were recognized and the total number of varieties listed was 27.

Although there are a dozen or more types of citrus fruits, only five or six are of major importance from a commercial standpoint. The most important of these grown for fruits are the sweet orange, *Citrus sinensis* (L.) Osbeck; the grapefruit, *C. grandis* (L.) Osbeck[2]; the acid citrus fruits, including the lemon, *C. limonia* Osbeck, and the lime, *C. aurantifolia* (Christm.) Swingle; and the mandarin orange group, including the tangerine orange, *C. nobilis* var. *deliciosa* Swingle, and the satsuma orange, *C. nobilis* var. *unshiu* Swingle. Other types that are of importance mainly as rootstocks are the sour or Seville orange, *C. aurantium* L.; the rough lemon, *C. limonia* Osbeck; and the trifoliate orange, *Poncirus trifoliata* (L.) Raf. In some foreign countries the sour orange, the pummelo (*C. grandis*),[2] and the citron (*C. medica* L.) are of relatively greater commercial importance than in the United States.

From the Orient the various types and varieties spread to other parts of the world along the trade routes. The citron reached the Mediterranean region at an early date, as it is mentioned by Theophrastus. The sweet orange was apparently not introduced into Europe until the early fifteenth century. The sour orange reached Spain by way of northern Africa. The lemon and the lime were apparently introduced into Europe about the same time as the sweet orange, and several varieties are described by Ferrarius and other writers. Lemon culture first became important in Sicily, Corsica, Genoa, and other parts of southern Europe.

On his second voyage to the New World in 1493 Columbus stopped off for 2 days early in October at Gomera, Grand Canary Island, where he purchased livestock and fruit and vegetable seeds, among which were "seeds of oranges, lemons, and citrons." He reached the island of Hispaniola on November 22, 1493, and in the course of establishing a colony he "set out orchards, planted gardens" (*40*). The historical records of introduction to other parts of the Americas have not been exhaustively searched, but citrus fruits were established at St. Augustine, eastern Florida, by 1579 (*12*) and in Peru before 1591 (*82*). They were introduced into southern California in 1769 by Franciscan monks at San Diego (*43*), and there were undoubtedly many similar introductions into Brazil, Mexico, and other regions settled by the Spanish. In Florida the sour orange, and to a lesser extent the sweet orange and the lime, escaped to the wild.

It is now known, however, that the so-called "wild lime groves" on the lower east coast keys of Florida were in fact planted out by

[2] *Citrus grandis* (L.) Osbeck, as here used, includes the type, the sour shaddock; and two varieties, (1) the commonly known grapefruit and (2) the pummelo, used solely as a salad fruit as explained in the text. The term pummelo should not be confused with pomelo, sometimes used as a synonym for grapefruit.

Henry Perrine, to whom in 1838 Congress had granted a tract of land 6 miles square on Biscayne Bay for the establishment of economic tropical plants. Before his death in the Indian Key massacre of 1840 he had established a nursery of upward of 200 species and selected varieties of useful tropical plants (*53*).

REGIONAL CHARACTERISTICS IN THE UNITED STATES

COMMERCIAL citrus growing in the United States presents striking contrasts, due primarily to climatic conditions in the main centers of production (fig. 1). In Florida at an early date the sweet orange, the tangerine orange, and the grapefruit found a congenial home; in California the sweet orange and the lemon have proved the basis for profitable industries, with grapefruit secondary in importance. Texas and Arizona have more recently come into the picture, especially for grapefruit production.

Differences in varieties and seasons of maturity are likewise in sharp contrast. In California two varieties of oranges, the Washington Navel and the Valencia, furnish fruit maturing from November to November, a year-round shipping season. In Florida three or four sweet orange varieties, together with seedlings, are generally required to give a shipping season from October to May. In California lemons are more or less everbearing, affording a supply throughout the year. The Florida and Texas grapefruit crops mature practically during the same season (the fall and winter months), the California and Arizona crops coming in somewhat later. Similar contrasts are to be noted with the rootstocks used in these regions. These and other regional contrasts will be discussed more in detail later.

Thus it will be seen that because of differences in climate and in variety adaptation, citrus fruits, with their highly important vitamins, are available to the American consumer throughout the entire year. In general it may be said that grapefruit has been America's chief contribution to citrus culture, its recognition in Florida as an appetizing breakfast fruit gradually changing this curiosity of the citrus family into a formidable rival of the sweet orange in the national dietary.

SOUTHEASTERN HUMID REGION

In the southeastern humid subtropical crops region, citrus development began in eastern Florida in the vicinity of St. Augustine and along the Indian River and in north-central Florida in the general vicinity of Palatka and Ocala as far south as Lake Monroe. On the west coast of Florida the development took place in the vicinity of Tampa Bay and southward. The outstanding pioneers in the introduction of citrus varieties during this period (1870–95) were E. H. Hart (fig. 2), H. S. Sanford, and Lyman Phelps. By the 1880's the industry in northeastern Florida was fairly important, but in the winter of 1894–95 it was practically wiped out by two severe freezes, and the center of the industry was moved farther south to the central ridge section and the southern coastal areas, where most of the citrus growing is now located. Today the industry is based primarily on the sweet orange, grapefruit, tangerine, and lime.

On the upper Gulf coast a citrus industry was established in the Delta district south of New Orleans, based primarily on the sweet

orange. Satsuma growing along the St. Johns River and near Jacksonville began about 1900, spreading thence westward—because of the cold resistance shown by this type during the 1894–95 and 1899 freezes—to the Gulf coast region in western Florida, Alabama, Mississippi, Louisiana, and Texas.

The early plantings of sweet oranges made in various parts of Florida consisted primarily of groves established from seedlings, and it was only later that the practice of budding improved varieties was gradually adopted with the introduction of meritorious early, midseason, and late sorts, beginning in the late 1870's. Since the citrus tree is relatively long-lived, the seedling groves, producing fruit mostly midseason in maturity, are still an important factor in Florida, and they produce approximately 30 to 40 percent of the State's total midseason sweet orange crop. However, budded varieties of recognized merit have been used almost entirely in new plantings and replacements for the last 40 years.

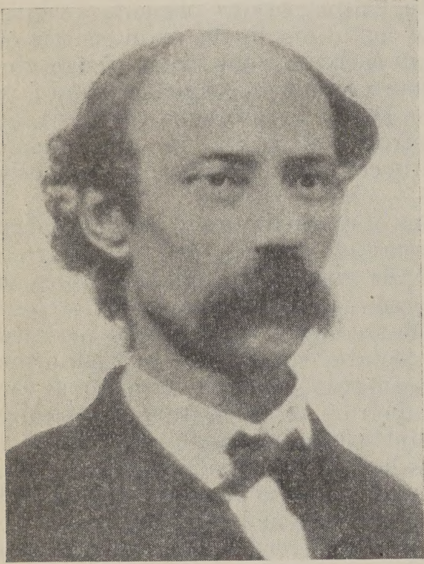

Figure 2.—Edmund H. Hart (1839–98), recognized as a skilled horticulturist and a pioneer in Florida citrus culture. His name is chiefly associated with the Hart's Late or Tardiff orange, now called Valencia, which he first brought to fruiting and introduced into general use in Florida during the 1870's.

Grapefruit first attained commercial importance in the United States. This was between 1880 and 1885, when the first grapefruit were shipped from Florida to the Philadelphia and New York markets. In Florida the industry received a set-back on account of the freeze of 1894–95, but it gradually expanded again, reaching a peak by 1929.

The lemon and the lime, which were classed together in early times, were introduced into the New World by the early Spanish explorers and settlers. The everbearing and rough lemons were among the early introductions into Florida, and the latter had escaped to the wild by the time permanent settlements became common.

Prior to the great freeze of 1894–95 the lemon industry of Florida was of considerable commercial importance. During the year previous to the freeze the annual shipments amounted to 140,000 boxes of lemons. Up to the present the industry has not been rebuilt, but recently attempts have been made to reestablish it. Limes are grown in southern Florida, chiefly on the keys, in Dade county, and in the south-central ridge section.

The mandarin oranges include the King, tangerine, and satsuma types. The tangerine was introduced into Europe from the Orient during the first half of the nineteenth century and was produced on

a commercial scale in Italy as early as the 1840's. It was introduced into Louisiana between 1840 and 1850 and later was brought to Florida, where it is grown as a fancy fruit to a greater extent than in California or Texas. Another member of this group, the satsuma, is outstanding in being the most frost-hardy of all the larger fruited citrus types. It is grown primarily in the upper Gulf coast region, with the chief center of production in western Florida and southern Alabama and Mississippi.

Southwestern Irrigated Region

In the southwestern irrigated subtropical crops region a citrus industry has been established in California, primarily in the southern coast and interior valley sections. In the southern coast section the industry is based almost entirely on sweet orange and lemon, and in the interior valley section on sweet orange and grapefruit. An extension into the irrigated section of Arizona occurred later, founded primarily on the grapefruit.

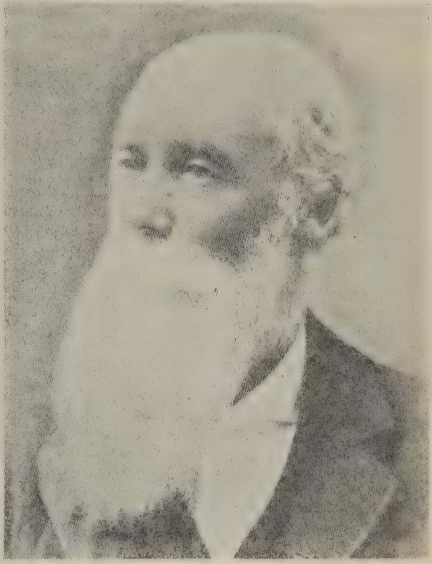

Figure 3.—Thomas A. Garey (1830–1909), pioneer California nurseryman, who made extensive introductions of citrus varieties during the period 1868–75.

Citrus seeds were disseminated from other parts of Mexico to the peninsula of Baja (Lower) California probably in the early 1700's, and later, in 1769, were introduced to Alta (Upper) California by Franciscan missionaries, who established a chain of missions for 400 miles along the coast. According to Coit (*11*), the early settlers secured orange trees from the missions, and a number of small plantings were found in private gardens in the 1830's and 1840's in the vicinity of Los Angeles. These early plantings stimulated further interest, and in 1857, trees were planted at old San Bernardino and Highlands, in 1865 at Crofton, and in 1871 on land now occupied by the city of Riverside. T. A. Garey (fig. 3), of Los Angeles, the outstanding nurseryman of that time, imported large numbers of important varieties during the period 1868 to 1875. His introductions were apparently from Florida, Australia, and southern Europe, as well as from Ellwanger & Barry, of Rochester, N. Y., and Sir Thomas Rivers, of Sawbridgeworth, England. In the southern and central parts of California the industry was only of local importance until after the completion of the Southern Pacific Railroad in 1876, when the first carload of fruit was shipped to St. Louis, Mo., arriving in good condition after a month in transit.

The grapefruit industry in the Southwest—California and Arizona—began after the introduction of the Marsh variety in 1890; the plantings of other varieties previous to that time did not prove profitable.

Great success in lemon culture has been achieved in California, particularly in the southern coastal region, which produces a large proportion of high-priced summer fruit.

Central Irrigated Region

In the lower Rio Grande Valley of Texas, in the central irrigated subtropical crops region, an industry has been established based primarily on the grapefruit and to a lesser extent on the sweet orange.

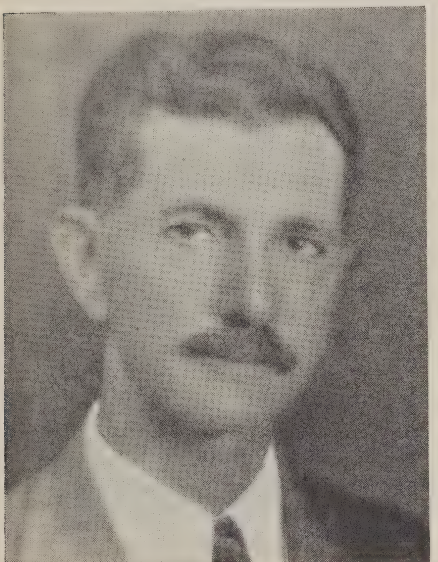

Figure 4.—**Charles J. Volz, pioneer Texas citrus grower since 1908, who demonstrated the value of sour-orange rootstock for citrus in the lower Rio Grande Valley of Texas. This demonstration proved to be a turning point in the development of the citrus industry in that section.**

As early as the middle of the last century scattered plantings of a few citrus trees could be found along the Texas Gulf coast, particularly from Victoria County southward to Brownsville on the Rio Grande. Experience had demonstrated by the beginning of the twentieth century that regular citrus crops could not be expected in the region above the lower Rio Grande Valley, on account of damage from low temperature (*48*). In the lower Rio Grande Valley—Cameron, Hidalgo, and Willacy Counties—the development of the industry may be grouped into three periods. (1) Up to 1899 citrus fruits were grown for home use and no particular attention was given to the subject of rootstocks. Seedlings and budded trees were planted. During this period, in 1869, the trifoliate orange was imported from northern China by William Saunders, of the United States Department of Agriculture, and it was used to some extent as a rootstock. (2) The resistance to frost shown by trees budded on trifoliate stock during the severe freeze of 1899 led to the extensive use of this stock during the following decade (*87*). Although the stock was valuable from the standpoint of frost resistance and encouraged the pioneer growers to make further attempts, it had the serious defects of dwarfing the scion variety and of being itself subject to foot rot and cotton root rot (*77*). (3) The observations of some of the outstanding pioneers, Charles J. Volz, Harry Banker, J. R. Robertson, F. E. Elliot, Max Melck, and A. P. Wright, beginning after 1900, made possible the growing of citrus fruits in commercial quantities.

Charles J. Volz (fig. 4), from Indiana, settled near Mission in Hidalgo County, Tex., in 1905. He began the planting of citrus in 1908 and clearly demonstrated the superiority of the sour-orange rootstock under the lower Rio Grande Valley conditions. Harry

Banker, from Oklahoma, who settled near Brownsville, in Cameron County, secured similar results with the sour-orange rootstock beginning in 1910 (*87*). With the solution of the rootstock problem the industry showed at first gradual and later rapid development. The citrus shipments from this section, consisting mainly of grapefruit, had reached 13 carlots in 1921 and increased to more than 5,000 carlots annually by 1931. Yields were cut down as a result of hurricane damage in 1933 and damage due to low temperature in 1933–34 and 1934–35, but the crop of 1936–37 reached a total of over 15,000 carlots. Fortunately for this new industry, the seedless type of grapefruit (Marsh variety and its pink-fleshed mutations) has been most heavily planted in Texas, and this has doubtless contributed to its favorable reception in many markets.

HAWAII, PUERTO RICO, AND THE PHILIPPINES

The sweet orange was introduced into Hawaii in 1792, and many citrus varieties have been cultivated there for over 100 years (*54*). The climate is well adapted to citrus culture, but for commercial production the situation is complicated by the presence of the Mediterranean fruit fly, which limits production to local needs.

While citrus fruits, especially the sweet orange, have been grown in a semiwild condition in Puerto Rico for perhaps 3 centuries, commercial planting did not begin until about 1900. The first plantings were largely of Florida orange varieties, but these were soon largely discarded in favor of grapefruit (*29*). The varieties most commonly grown are the Duncan and the Marsh. For budding stocks, rough lemon, sour orange, and seedling grapefruit have all been successfully used, the rough lemon being favored for rapid growth and early production and especially for the lighter grades of soil. Wind damage has caused frequent losses of trees and fruit and has directed attention to the use of such plants as bamboos and casuarinas for windbreaks.

Owing to the fact that the trees bloom intermittently, Puerto Rico is enabled to ship grapefruit over a long season, a summer crop often maturing from a previous fall bloom. Production for several years past has averaged about a million boxes, of which approximately 25 percent is marketed as canned grapefruit. Puerto Rico is credited with having initiated the canning of grapefruit "hearts", a product that has grown rapidly in favor and has made grapefruit available at all seasons and in many localities where fresh fruit seldom is offered. Orange shipments from Puerto Rico, amounting to a half million boxes in good seasons, consist largely of so-called "wild oranges", which come in a considerable measure from seedling trees cultivated as shade trees on coffee plantations.

In the Philippines citrus fruits have been grown for centuries, forms of *Citrus hystrix* DC. (kalpi), *C. mitis* Blanco (calamondin), and *C. grandis* (pummelo) being native to the islands. It is only in recent decades, however, that attention has been given to growing the fruit commercially. Wester (*88*), beginning about 1910, brought together an extensive collection of citrus varieties at Lamao, few of which proved adapted to Philippine conditions. The mandarin oranges as a class have proved best suited to commercial culture,

and a local variety known as Batangas mandarin is being grown on a considerable scale chiefly for the Manila market. The Batangas, the King, and the Szinkom mandarins, several pummelo varieties—including the Siamese—and the Valencia orange constitute most of the recent plantings. Genetic studies and hybridization work have been inaugurated by Torres, and one hybrid variety, Szinbat (Szinkom × Batangas), has been introduced. It is characterized as productive, of good quality, and resistant to wind injury. Further breeding and selection work is in progress, special studies being made of polyembryony—to be discussed later—in scion and stock varieties.

BREEDING MATERIALS

THE citrus breeder is concerned with two kinds of plant materials within the Rutaceae—the citrus group proper, containing the types closely related to the widely known sweet orange, and various species in genera somewhat less closely related. The first or citrus group contains all of the valuable types cultivated for their fruits or used as rootstocks, and the second is of value in some instances as stocks, as breeding material, and in furnishing a clue to the evolutionary development of the branch of the Rutaceae to which the citrus fruits belong.

The citrus group proper is characterized by great diversity in morphological characters, and this has led some systematic botanists to the multiplication of species. The classification of Swingle (*68*), however, is conservative, has been widely accepted, and is used in this report. The only exception made is in the case of *Citrus grandis*, where it has been necessary to recognize two varieties besides the type species.[3] The horticultural differences in a number of cases are so great, as will be pointed out in the discussion of dessert quality later, that the single type designation is quite inadequate.

The following types commonly grown for their fruits or as rootstocks are in the three genera *Citrus*, *Fortunella*, and *Poncirus*:

Sweet orange, *Citrus sinensis* (L.) Osbeck.
Sour orange, *C. aurantium* L.
King orange, *C. nobilis* Lour.
Tangerine orange, *C. nobilis* var. *deliciosa* (Tenore) Swingle.
Satsuma orange, *C. nobilis* var. *unshiu* (Mak.) Swingle.
Shaddock, *C. grandis* (L.) Osbeck.
Grapefruit, *C. grandis*.
Pummelo, *C. grandis*.
Citron, *C. medica* L.
Lemon, *C. limonia* Osbeck.
Lime, *C. aurantifolia* (Christm.) Swingle.
C. ichangensis Swingle.
Kalpi, *C. hystrix* DC.
Calamondin, *C. mitis* Blanco.
Kumquat, *Fortunella* spp.
Trifoliate orange, *Poncirus trifoliata* (L.) Raf.

The citrus breeder is fortunate in possessing material that presents so many diversities—in dessert and keeping quality, season of maturity, resistance to disease, and regional adaptation. All of these will be developed in detail in the following text, but the dessert quality of the types will be discussed at this point.

[3] See footnote 2, p. 752.

Character and Uses of the Fruits

Some of the fruits listed above—sweet orange, grapefruit, lemon, and lime—have become well known to northern readers and need to be only briefly differentiated; a few, however, are little known and will require more detailed descriptions. In general it may be stated that the taste qualities of mature citrus pulp and juice are dependent on various combinations of sugars, acids, glucosides, esters, and peel oil. The first two, the sugars and acids, are the basic matrix and give variations from sour through tart, sweet, and insipid, and the latter contribute bitter and aromatic principles. The bitter principle, furnished by glucosides, is apparent only if it is in solution in sufficient amount in the juice (*5*, *78*, *79*). This is normally not the case except in such types as grapefruit and lime. The aromatic quality contributed by peel oil is important in some cases.

In most commercial varieties of sweet orange the sensation of sweetness predominates, combined with a slightly perceptible tartness. In most varieties the quality contributed by esters is slight, but in such varieties as Pineapple the suggestive "pineapple" ester is outstanding.

In the mandarin orange or free-peeling group, the tangerine oranges are characterized by the pleasant "tang", which is due to esters. The King and satsuma oranges in this same group have taste qualities similar to those of the sweet orange.

In grapefruit the bitterness of the glucoside naringin gives the sprightly taste added to the mild acidity that makes the fruit outstanding as a breakfast appetizer.

The pummelo, as distinguished from the sour shaddock, is used only as a salad fruit. The large juice sacs are separated from the locular wall tissues and are served like any other salad. The flavor in the better varieties is due to a very slight acidity and the presence of only a very little glucoside, but it is predominantly sweet, and inimitable quality is contributed by esters.

In lemon and lime, acidity is of first importance. A good acid citrus fruit, as pointed out by Traub and Robinson (*80*), should have from 6 to 7 percent of acid. In lime the characteristic glucoside, which has not been studied in detail, lends the "lime" taste. The peel oil of lemon and lime also gives desirable qualities.

The citron is used entirely as a preserve. The kumquat is used both in preserving and in table decorations. It is also eaten entire, out of hand. Two general types are recognized, sweet and sour, in both of which the rind has little of the pungent oil common to most citrus fruits.

In the case of hybrids, intermediates have in some instances been secured, especially in the tangelo oranges—hybrids between the grapefruit and the tangerine orange. In these hybrids, as a rule, the esters are predominant in distinguishing the flavor of the new fruits from the common sweet orange. In the Perrine lemon, a hybrid between the lemon and the lime, there is a mild suggestion of the lime glucoside.

When hybrids between citrus species first appeared it was customary to apply various compound names, such as tangelo, tangor, oranguma, limelo, lemelo, etc., to indicate the parentage. It was soon realized that this would lead to confusion from the horticultural

viewpoint, since some crosses gave rise to more than one horticultural or market type. The grapefruit-tangerine cross (tangelo), for instance, gave rise to forms like the now generally known tangelo orange, and also varieties that resemble the grapefruit in structure and juice quality but with the rind, flesh, and seed color of the tangerine. A strict application of the term "tangelo" would have included both of these forms. The difficulty was overcome by the decision to place hybrids for purposes of horticultural classification with the well-known types that they most resemble, and to use the interspecies compound designations only in their scientific application. On this basis most of the tangelos already introduced, being more like the sweet orange in structure and use, were designated as a group of the sweet orange, possessing relatively high quality with special reference to a pleasing blending of esters, sugars, and acids. Such a class would naturally contain also such hybrids as the Umatilla (oranguma), a cross between the sweet orange and satsuma orange, but very similar to the other tangelo oranges, and also the Temple, apparently a naturally occurring hybrid between the tangerine and a grapefruit variety similar to the Tresca.

Representatives from a great number of related genera, *Glycomis*, *Claucena*, *Chalcas*, *Feronia*, *Feroniella*, *Aeglopsis*, *Aegle*, *Swinglea* (*Chaetospermum*), *Balsamocitrus*, *Lavanga*, *Hesperethusa*, *Triphasia*, *Severinia*, *Citropsis*, *Atlantia*, *Eremocitrus*, and *Microcitrus*, have been introduced by the United States Department of Agriculture during the last 25 years. These are listed in table 6 in the appendix. Some of these may prove of value in citrus breeding and as rootstocks. Although certain species have entered to some extent into hybridization work, no hybrids of immediate value have been secured up to the present. The material, however, is valuable to the breeder from another standpoint, for it presents an opportunity for an evolutionary approach to the study of relationships within the group.

GENERAL TRENDS AND PROBLEMS

The early history of citrus improvement in the United States is concerned almost entirely with the introduction of varieties from other citrus-producing regions, mainly through private initiative. This period extended to the 1870's in this country. Toward the end of the nineteenth century, in the United States, the number of varieties was increased by the addition of those originating as chance seedlings and possibly by bud mutations accidently propagated. Still later, improved types appeared as the result of artificial cross-pollination. Breeding work was undertaken by the Department of Agriculture in 1892, and the the State agricultural experiment stations in California in 1910, in Florida in 1924, in Alabama in 1933, and in Texas in 1934.

Problems Peculiar to Citrus Breeding

The breeding of citrus fruits presents two problems not met with in the case of the usual annual crops such as grains, which can be grown in great numbers on a relatively small area at small expense.

First, as a rule it takes from 6 to 10 years to fruit a seedling citrus tree unless the variety is top-worked on an older tree, in which case the time will be cut in half. The trees are expensive to produce and to

test out in orchard formation on various soil types and under various climatic conditions. It is necessary, therefore, to plan breeding experiments so that only progeny are grown that promise varieties of immediate value or additions to the knowledge of citrus genetics. With such a handicap, the work has not progressed at a very rapid rate.

The other difficulty is due to the phenomenon of polyembryony—meaning "several embryos per seed" (fig. 5). In the case of plants reproducing by seeds, each single seed as a rule gives rise to one seedling, which is the result of the union of the male gamete (reproductive cell), contributed by the pollen grain, and the female gamete (egg cell), contained in the ovary of the flower. In each of these gametes the number of chromosomes has been normally reduced by half preparatory to reproduction (the haploid number of chromosomes), and the union of the two results in a complete complement of chromosomes, called the diploid number, which is characteristic of all of the body cells of the individual plant as distinguished from the sex cells. In the case of the citrus seeds, however, a normal embryo produced by the union of the male and female gametes may be present, and in addition one or more—sometimes as high as 15—additional embryos that have arisen from projections into the embryo sac of the surrounding maternal tissue (nucellar tissue). When these projections develop into embryos they have the full chromosome complement (diploid) of the mother plant without the union of two gametes. Citrus types and varieties may vary greatly in the number of nucellar

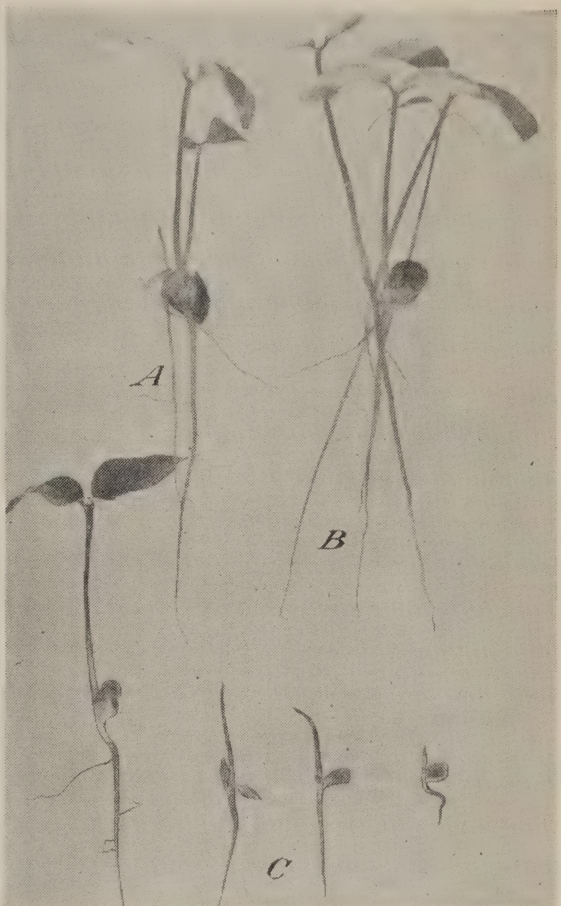

Figure 5.—Nucellar embryony in citrus, showing four seedlings sprouting from single seeds (McCarty grapefruit): *A*, One vigorous seedling and three relatively less vigorous; *B*, four vigorous seedlings; *C*, similar to *A* after separation. (See also fig. 17, showing cytological details.)

embryos produced. Seedlings that develop from nucellar embryos are called apogamic seedlings (literally, "without marriage").

Unless the parents have unlike vegetative characters, it is not possible to distinguish the sexually produced or hybrid embryo from those that arise by nucellar budding, though in the latter, of course, only the characters of the female parent will appear. This means that a great many more seedlings must be grown to the point where they can be distinguished than in the case of crops producing only normal or seminal seedlings. Citrus breeding, therefore, will continue to be even more costly than ordinary tree-fruit breeding unless a method can be worked out to achieve practical control of nucellar embryony.

Thus it is natural to expect relatively slow progress. The results from cross-pollination followed by inbreeding and selection, and from back-crossing on the parent types, will not be available in a few seasons but only after a considerable period of time. However, the earlier pioneers in this field have laid the foundation, and in the future it is probable that the rate of progress can be considerably accelerated.

Methods of Breeding

Fortunately no problem is presented with reference to controlling pollination in citrus. The flowers are relatively large and the ordinary bagging technique with brown-paper bags has proved sufficient. In practice the flowers are emasculated before pollen is shed and then bagged. They are pollinated soon after opening, and the bags, which were removed for pollination, are replaced and left on until the petals have fallen and the fruit begins to grow. To protect from loss by dropping, the fruits are usually covered with cheesecloth bags.

Pollen is gathered from flowers that have been bagged when still closed and is used immediately unless flowering of the parents desired does not overlap, in which case the pollen is stored for later use. Kellerman (*35*) has shown that citrus pollen dried over concentrated sulphuric acid and sealed in glass vacuum tubes at about 0.5 mm pressure can be kept in a viable condition for more than 2 months.

When the seeds are removed from the harvested mature fruits secured as a result of artificial pollination, they are thoroughly washed and are planted at once in flats, for the germination percentage usually decreases if they are allowed to dry in the air. The flats containing the seeds are placed in a coldframe to prevent damage by heavy rains. When seedlings are 6 to 18 months old they are planted in nursery rows, usually 12 by 6 feet apart, and given good culture. As soon as the fruiting stage is reached, usually in 5 years, or sooner if top-worked on old trees, detailed records are taken of tree and fruit characters, and all seedlings that show no immediate promise or appear to be of no value for future breeding are destroyed. These records determine the apparent worth, if any, of the plants as varieties for cultivation, and also serve as a basis for working out genetic principles.

The seedlings are tested for vigor, including disease resistance, bearing capacity, and regional and rootstock adaptation. The fruits are tested for size, shape, juice percentage, season of maturity, number of locules and seeds, rind thickness, percentage of "rag", percentage of sugars and acids, effective acidity (pH) of the juice, and the

flavor of the juice. Out of a great number of seedling individuals only a very few are finally selected for introduction, and these are released only after favorable performance in preliminary fruiting tests in a number of locations.

Objectives of the Breeder

The first consideration in citrus breeding is excellent dessert quality. What constitutes high quality has been previously discussed, and we pass to the consideration of tree and other fruit characters that the breeder has in mind when making his crosses and selections.

The tree (scion variety) should be compact in habit, but a vigorous grower and a prolific bearer. It should be resistant to the common citrus diseases and to low temperatures, and congenial with the rootstock or rootstocks used in the region. The fruit should mature at the proper season or seasons to suit market needs. There are also other characters of importance, such as thornlessness.

The fruit should have excellent dessert quality and contain few or no seeds; the shape and size should be suited to commercial requirements and to ease in packing; shipping or keeping quality, including resistance to storage diseases, should be good; the exterior, including texture and color of rind, should be attractive; and, in particular, the vitamin C content should be up to the standard. With the rapid growth of a new industry in canning "hearts" and juice of both grapefruit and orange, special attention may need to be given to the requirements of this promising industry. For instance, it has already become evident that the pulp of Marsh grapefruit lacks the firmness necessary in a good canning grapefruit. With the growing tendency to utilize citrus fruits in juice form and in mixed drinks, the high color of the juice characteristic of the tangelo group of hybrids is proving a decided advantage.

The tree used as a rootstock should be adapted to the soil and climatic conditions, be free from or resistant to trunk and root diseases, and produce a high percentage of nucellar embryos, and it should not be so vigorous in growth as to make the fruit of the scion coarse, of poor texture, and comparatively low in total solids (sugars and acids) and therefore insipid in taste (*6*, *80*).

As the margin between production costs and sales returns becomes narrowed with increasing supplies of citrus fruits, any adaptation that might lessen the cost of production becomes vitally important. This places emphasis on disease resistance in any breeding program, to reduce both expense for grove sanitation and losses due to infected trees and fruit. In citrus the list of such diseases is quite extensive and varies with citrus types and varieties.

The task of breeding for resistance to injury from insect and other animal pests on plants presents the major difficulty of developing a practical technique.

In Florida the chief citrus diseases are melanose, affecting tender twigs, leaves, and immature fruits, and stem-end rot, affecting mature fruit, both caused by *Diaporthe* (*Phomopsis*) *citri* (Fawc.) Wolf; sour orange scab (*Elsinoë fawcetti* Bitancourt and Jenkins), affecting leaves and fruits; key lime anthracnose (*Gloeosporium limetticolum* Clausen); foot rot (*Phytophthora parasitica* Dastur); and psorosis, cause undetermined.

In the Southwest, brown rot gummosis and foot rot (*Phytophthora citrophthora* (Sm. and Sm.) Leonian and *P. parasitica*); psorosis; and shell bark (*Diaporthe citri*) are of major importance; and in the lower Rio Grande Valley gummosis, scaly bark, and stem-end rot (melanose).

Achievements and Future Possibilities

In spite of the peculiar difficulties encountered in citrus breeding, definite achievements can be recorded, and the outlook for the future is most encouraging. The work in the past has shown that worthwhile results may be secured from appropriate crosses and that important strains and varieties may arise by bud mutation. In addition a beginning has been made in laying a foundation of genetic principles.

The work in citrus hybridization carried on by the Department of Agriculture workers since 1893 has shown that the combinations of grapefruit and tangerine and of lemon and lime give the most promising results. The first have given rise to high-quality fruits known as the tangelo oranges, and the latter to a high-quality lemon, the Perrine. The work of Frost, of the California Agricultural Experiment Station at Riverside, has shown that crosses within the mandarin orange group give worth-while results.

Apogamic seedlings from crosses have also given rise to important varieties in grapefruit and in sweet, sour, and satsuma oranges. Bud selection has given superior strains of known varieties and has served to stabilize standard varieties. Crosses with more distantly related relatives of citrus, *Citrus* × *Poncirus*, citrange × *Fortunella*, citrange × calamondin, etc., have proved interesting from the genetic standpoint and have also given some concrete types of possible value in horticulture—citrange, citrangequat, and citrangedin. Reference to particular hybrids in which definite objectives have been attained are found in the text and in table 6.

Thus the ground work has been laid by the earlier workers. With the wealth of breeding material and the increase of interest in this field, research in citrus breeding may be expected to show greater progress in the years to come.

Some idea of what the future holds in store as a result of citrus breeding can best be gained from the following quotations contained in the report made by H. B. Frost, actively engaged in citrus breeding at the Citrus Experiment Station, Riverside, Calif., in connection with the cooperative survey of plant and animal breeding:

> If we wish to produce a variety or strain that is very similar to a standard variety, such as the Valencia, but superior in some important feature, such as eating quality, generative seedlings from either selfing or narrow crossing are very unpromising, for two reasons: (1) they are usually weak and very unproductive, and (2) they are usually very unlike the parent or parents. The best chance of success, although a very uncertain one, seems to lie in the discovery of superior bud-variation forms. Such forms may be found, of course, either as "limb sports" or as whole trees which have happened to be budded from variant branches. They may also be found as seedlings derived from nucellar embryos that happen to be formed on a variant branch; in this case the seedlings are likely to be indistinguishable from other nucellar seedlings until they produce fruit. On the basis of the time and expense required, the search for bud variations in commercial orchards seems more promising than the growing of seedlings. A good new bud-variation type may in some cases, however, be variable because of

mixture with the parent variety in the same shoots to form a chimera, and the growing of seedlings may then be the best method of getting the new type separated from the parent variety. Variability may in some cases be inherent in the constitution of a new form, however, so that it will never become stable.

X-ray treatment probably can be used, as it has been with other plants, to increase greatly the frequency of new genetic variations. It seems most likely to be useful by producing variations in nucellar seedlings.

For the production of new varieties of superior quality but with flavors very unlike those of the present varieties, the great variability of hybrids offers much promise, since we can use wide crosses, which commonly give vigorous hybrids. Various hybrids of the tangelo and tangor groups, which are hybrids of mandarins with grapefruit and with sweet orange, that have been introduced by the United States Department of Agriculture, offer unique and very pleasant flavors. It is now probable, however, that the best opportunities for securing superlative quality are to be found in crossing within the mandarin species or group of species, and therefore, it is very fortunate that certain crosses between mandarin-group varieties produce vigorous hybrids.

It is advisable to make some further trial of the production of triploid hybrids by pollinating tetraploids by diploids of other species (or of other sections of the mandarin "species"). The only tetraploid form which at present seems to have much promise for such use is the tetraploid Lisbon lemon, which combines good seed production, comparatively low chromosome irregularity, and high proportion of generative progeny.

The evidence on which these suggestions are based has only partly been secured at the Citrus Experiment Station, and that on the results of selfing has very largely been obtained in Dr. H. J. Webber's root stock experiments. The nature of the work has ranged from chromosome counts and systematic records of various tree and fruit characters, to the determination of the agreeableness of fruit flavors. Any extensive gene analysis is clearly impracticable in citrus, yet certain evidence has been obtained which seems to have definite significance for general genetic theory, when interpreted on the basis of gene analysis made on more favorable organisms.

The problems that most concern the citrus breeder have been listed by Frost as the determination of—

(1) The generality of the reduction of vigor with selfing and narrow crossing. (2) The extent to which the proportion of nucellar seedlings can be predicted from counts of total embryos. (3) (*a*) The extent to which triploids are unproductive of fruit, as compared with diploids of the same ancestry. (*b*) The extent to which triploids can be produced by crossing diploids with tetraploids. (*c*) The frequency with which triploids occur from crosses between diploids. (4) The extent to which the prospects of high vigor, productiveness, good flavor, and other horticulturally desirable characters in crossing can be inferred from knowledge of the species or smaller taxonomic group to which a variety belongs, on the basis of trial of other varieties of the same group. (5) The frequency with which new genetic types arise by bud variation, and the extent to which this process can be speeded up by X-ray treatment of seeds, pollen, etc. (6) The best methods of modifying physiological conditions to secure high seed production in crossing, and, if possible, high proportions of generative embryos.

With the present facilities, problems named under 1 to 4 above may be solved partially, and to a much smaller extent those under 5 and 6 in the list.

IMPROVEMENT OF CITRUS VARIETIES

The improvement of citrus varieties will now be briefly discussed on the basis of citrus types—sweet orange, mandarin oranges, grapefruit, acid citrus fruits, and minor citrus fruits. In each case the varieties will be considered by regions. Following this, citrus bud selection and citrus rootstocks will be considered under separate headings.

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Sweet Orange Improvement

Florida

In Florida the bulk of the citrus crop is produced between October and June. Good early-maturing and very late-maturing varieties are of most importance from the breeding standpoint. The sweet orange varieties of Florida have been described by Hume (*32*).

EARLY VARIETIES

Early-maturing sweet orange varieties for Florida are relatively scarce, and it is desirable to give this fact due weight in any citrus-breeding project.

The Hamlin is one of the early varieties usually recommended. It was discovered in a grove planted in 1879 near Glenwood, which later came into possession of H. E. Hamlin. Under the best cultural conditions the acidity and sweetness are well blended, giving it excellent flavor; the rind is smooth and glossy; seeds are none too few; the season is October and November and later. Recent reports indicate that it is sensitive to overfeeding and other unfavorable growing conditions, which may lead to fruit splitting, riciness of pulp, and poor juice quality.

The Parson Brown variety was introduced by C. L. Carney, of Lake Weir, about 1878, having originated at Webster in a seedling grove owned by Parson Brown. Acidity and sweetness are fairly well blended if the fruit is picked early; seeds, 10 to 19; season, October and November.

Early sweet oranges usually have poor rind and flesh color when harvested at the beginning of the season. This is a deficiency that might be remedied by breeding methods.

The results thus far look promising. A hybrid, the Orlando tangelo orange (fig. 6), introduced by the Department in 1931 and resulting from a cross of the Bowen grapefruit pollinated by Dancy tangerine, is early in maturity and can be harvested over a long season. The variety is highly resistant to citrus scab. When first harvested in late September or early October the rind color after degreening with ethylene is a beautiful light yellow, but later in the season it takes on a natural deep reddish-orange color. It is medium in size, and the flesh color is deep orange. Its main defect is its seediness. Such a defect can apparently be overcome in future breeding work, as will be pointed out later.

MIDSEASON VARIETIES

A large number of midseason varieties were named and introduced beginning in the 1870's. Among these the outstanding ones are the Homosassa and Pineapple. The Homosassa is a variety of excellent quality, with a sprightly, rich, vinous flavor; seeds, 20 to 24; season, December to February. The Pineapple is the outstanding midseason variety, having a glossy rind of deep orange color, vinous and sprightly in flavor; seeds rather large and numerous. It originated near Citra, Marion County, and received its name from the fine aroma reminiscent of the pineapple. It is today the most important midseason sweet orange in Florida.

The navel type of sweet orange is not suited to the Florida climate. Although a number of varieties have been introduced, they have not proved successful as the Washington Navel has in California.

Two midseason tangelo oranges, of the same parentage as the Orlando variety, introduced by the Department in 1931—Minneola (December–January) and Seminole (February–April)—are outstand-

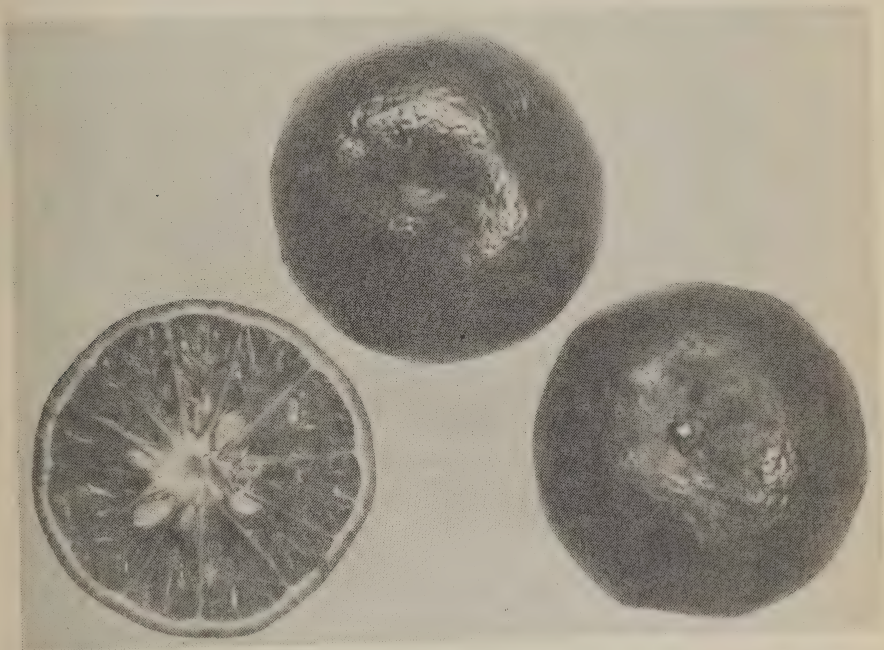

Figure 6.—Typical fruits of Orlando tangelo orange (originally introduced as the Lake variety), a hybrid between grapefruit (♀) and tangerine (♂); remarkable for earliness, maturing in October and November; highly resistant to scab. Introduced by the United States Department of Agriculture.

ing from the standpoint of dessert quality, the Minneola especially having the most delicate blending of esters, sugars, and acids. These fruits have deep tangerine rind and flesh color, and their shipping quality is good. Like the Orlando tangelo orange, the Seminole (fig. 7) is highly resistant to citrus scab, the Minneola partially resistant. The fruits are somewhat seedy.

LATE VARIETIES

The sweet orange industry up to the 1870's was based on seedlings and clones producing early and midseason fruits. An event of great importance took place when, early in the 1870's, the late type of sweet orange, now called Valencia (fig. 8), was introduced into Florida by S. P. Parsons, a nurseryman of Long Island, N. Y., and Palatka, Fla. Parsons had secured it from Thomas Rivers in England, who had imported it from the Azores and had cataloged it under the name "Excelsior." Parsons gave trees to E. H. Hart (fig. 2), of Federal Point,

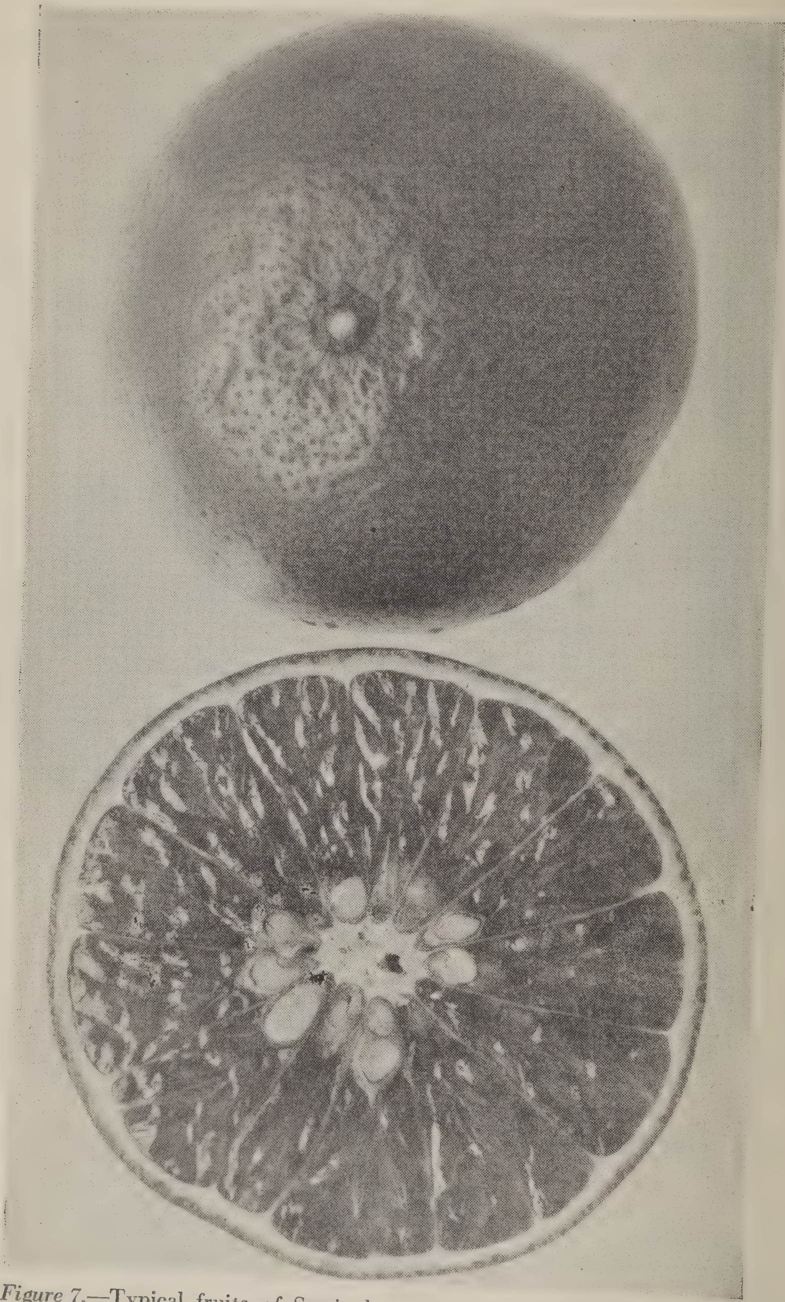

Figure 7.—Typical fruits of Seminole tangelo orange, a hybrid between grapefruit (♀) and tangerine (♂); midseason to late in maturity; replacing the older Sampson variety because of its high color and flavor, resistance to scab, and good shipping quality. Introduced by the United States Department of Agriculture. (Natural size.)

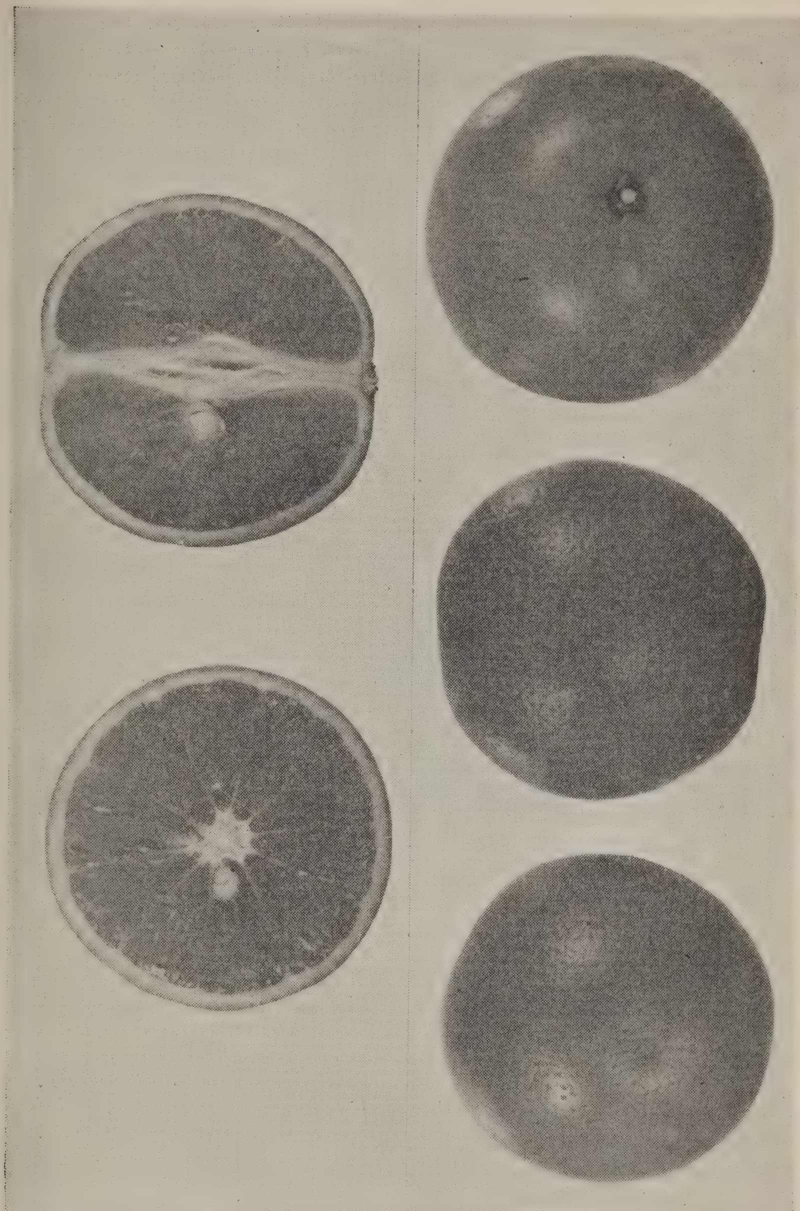

Figure 8.—Valencia orange, typical of the variety as grown on sour orange rootstock in Orange County, Fla. It is characterized by late maturity (March to June in Florida), firm flesh and rind, and fairly high content of citric acid, contributing to its good holding and shipping quality. It is commercially seedless, having normally two to five seeds.

Fla. Having lost the label, Hart distributed the trees under the name of Hart's Late or Hart's Tardiff. The variety was exhibited before the Florida Fruit Growers Association on April 25, 1877. The outstanding characteristic of this variety is its late maturity. Its season extends from March to June.

The variety was also imported into California, in a lot of citrus varieties from Thomas Rivers, by A. Chapman, of San Gabriel, Calif., between 1870 and 1872. One of these varieties, labeled as a navel, turned out to be a late-ripening nonnavel variety that fruited after the other varieties were off the market. The variety was named Valencia at the suggestion of a Spanish laborer, and Chapman sold it under the name of Valencia Late. Nurserymen in California had purchased stocks of Hart's tardiff, and a great many trees had been set out. By the time it was discovered that the Valencia and Hart's Tardiff were identical, the variety had attained commercial importance in California, and the name Valencia was retained.

A variety similar to the Valencia, named Lue Gim Gong, for the originator, and introduced in 1912 by the Glen St. Mary Nurseries, is described as very late in maturity. It is now generally regarded as a strain of Valencia, from which it originated as a seedling.

The production of a tangelo orange (Umatilla), which resulted from the pollination of the satsuma by the Ruby sweet orange and was introduced by the Department in 1931, indicates what may be accomplished by breeding methods in the creation of late-maturing varieties. In contrast with the parents—satsuma, early maturing, and Ruby, sweet midseason—the hybrid matures its fruit in late February, March, and April. The variety is highly resistant to citrus scab; the fruits are medium to large in size; the rind and pulp color is deep orange, and the quality is excellent. Seed content is variable.

To sum up: At the present time the sweet orange industry in Florida is based primarily on two early varieties, Hamlin and Parson Brown; on midseason seedlings and two midseason varieties, Pineapple and Homosassa; and on one late variety, Valencia.

California

In California one early and midseason navel and one late nonnavel variety have proved sufficient to produce an orange crop every month in the year.

Contrary to popular opinion, the navel type of sweet orange is not a modern product. It was described and pictured by John Baptisti Ferrarius in 1646 and is apparently of early origin. As early as 1820 the Bahia form of the navel orange had made its appearance in Brazil, where orange trees had been introduced by the Portuguese settlers. Its excellent qualities were soon recognized, and the variety was extensively propagated in the vicinity of Bahia. Even at this early date the variety seems to have been subject to bud mutation, and inferior types appeared that were unintentionally propagated and introduced in South Africa and Australia. Those that reached Australia also included desirable types.

The Bahia type of navel orange was first introduced into Florida in the 1830's, but the trees were killed during the freeze of 1835. A shy-bearing form of Bahia navel was introduced into California in the

early 1870's. The strain was secured from S. B. Parsons, Flushing, N. Y., who had received it from Thomas Rivers in England. In the early 1870's an inferior type of navel orange was imported from Australia into California, which set the precedent for referring to inferior strains as the Australian navels to distinguish them from the superior Bahia strain.

The story of the Washington Navel orange is a dramatic illustration of the value of superior varieties of economic plants. In 1870 the citrus industry had begun in California, but there was no outstanding early and midseason variety of sweet orange generally adapted to the climate. The early mission seedlings and varieties introduced after the middle of the nineteenth century were being tested out by various growers, but there was a lack of standardization in quality. The value of alertness in using the plant material that has been produced as a result of centuries of selection is nowhere better illustrated than by the timely action of the late William Saunders (fig. 9), then superintendent of gardens and grounds of the United States Department of Agriculture, Washington, D. C.

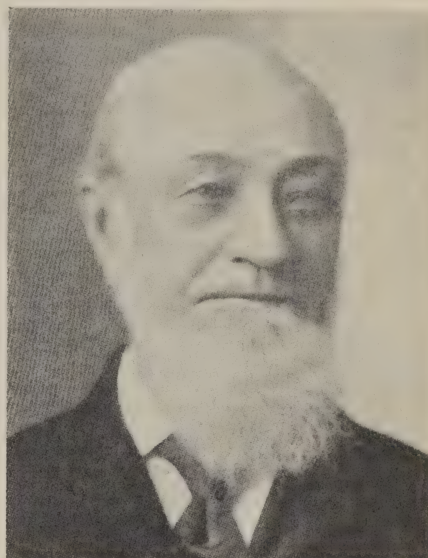

Figure 9.—William Saunders (1822–1900), superintendent of gardens and grounds of the United States Department of Agriculture at Washington, D. C., through whose efforts the Bahia navel orange was successfully introduced from Brazil in 1870. Three years later trees propagated by Saunders were planted in California and, under the name of Washington Navel, became the basis of an epoch-making industry.

In 1870, through the kind assistance of a missionary stationed at Bahia, Saunders imported from Brazil 12 navel orange trees in tubs. These were housed in the Department greenhouse at Washington, and propagations were made for distribution to the regions adapted to citrus culture. The first propagations were sent largely to Florida and California, but at least one of this lot is still maintained by the Department at Washington. Mr. and Mrs. Luther C. Tibbets were attracted to the settlement at Riverside, Calif., and early in 1873, before starting her journey, Mrs. Tibbets visited the Government propagation gardens at Washington, where Mr. Saunders gave her two Bahia navel trees. These were carried to California and planted beside the Tibbets' cottage in Riverside (fig. 10). In February 1879 the fruit was awarded first prize over other navels exhibited from Orange County, and these two trees were used as the source of extensive plantings. The variety was referred to as the Washington Navel to distinguish it from the Australian importations. An attempt was made to change the name to Riverside Navel, but this proved

unsuccessful. The great superiority of the Washington Navel (fig. 11) was soon recognized, since it apparently was ideally adapted to the climatic and soil conditions of California and produced a fruit of high quality with the highest market appeal. The best strain of Washington Navel, according to Shamel and associates (*61*), is characterized by an—

open and somewhat drooping habit of growth and dense foliage with large, oval, dark-green leaves. * * * Under normal conditions no pollen is produced by the anthers of the flowers. * * * The fruits * * * are obovoid in shape and generally of medium to large size. The rind is of medium thickness, and the texture is smooth and grained. The color of the fruit is bright orange; the rag is tender and comparatively small in quantity; the juice is abundant and of superior quality, having a pleasing and sprightly subacid flavor. The fruits are seedless, and the navel usually is small, sometimes rudimentary, with no development except in the rind.

By 1885 enterprising nurserymen had introduced most of the important varieties of the world, which were tested in comparison with the local seedlings of special merit. Less profitable varieties were rapidly eliminated, and by 1900 the area planted to the Washington Navel was larger than that of all other varieties in the State. It is now generally recognized that one of the outstanding events in the economic and social development of California was the introduction of this orange in 1873. During the period of more than 60 years following, a great industry has been built up from the two small trees planted by Mrs. Eliza Tibbets.

The Valencia variety of sweet orange, introduced into California and Florida between 1870 and 1872 as already detailed, is the other outstanding orange variety in the State. These two varieties are grown almost to the exclusion of others. Climatic conditions vary widely because of differences in rainfall, protection by mountain ranges, the moderating influence of the ocean, and other factors. These affect the ripening period of fruit varieties so that the same variety matures at different times in various regions. When this is coupled with "tree storage" in the case of the Valencia, which holds its fruit in good condition for several months, the combination results in a marketable fruit crop throughout the year. This tree storage is made possible by the dry summer climate with comparative freedom from fruit-destroying fungi, together with other climatic factors contributing to a long ripening season. The movement of Washington Navels begins in November and ends in May. The Valencia crop is marketed from May to November and, as a rule, overlaps by several weeks the period when navels are shipped.

Frost (*21*) reports that the Citrus Experiment Station of the University of California, at Riverside, has recently introduced a good early nonnavel variety, Trovita, which has pollen and a few seeds. This variety originated as one of three seedlings grown from Washington Navel seeds accidentally found. It is pointed out that this may be a promising variety in the hotter citrus districts because of its seeding tendency, since the seedless Washington Navel often fails to set fruit under these conditions. The fruit of the new variety is much like that of Washington Navel, but the navel structure is usually absent or rudimentary.

Figure 10.—Tree of the Washington Navel orange at Riverside, Calif., the lone survivor of the original budded trees of this variety sent to California in 1873, propagated from the introduction made in 1870 from Bahia, Brazil, by William Saunders, Washington, D. C. A tablet in memory of Mrs. Eliza Tibbets, who first planted this navel orange and brought it to fruiting, stands near the tree.

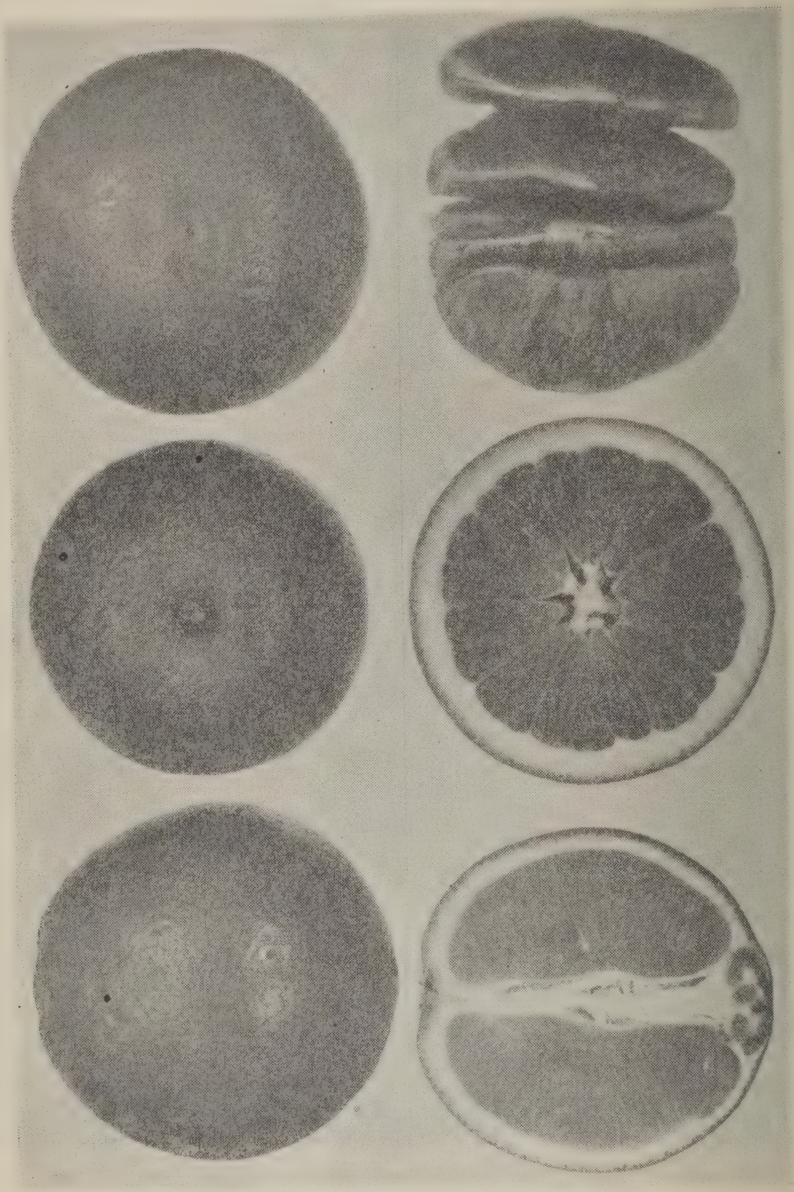

Figure 11.—Washington Navel orange fruit, typical of the variety as grown at Riverside, Calif., showing solid but juicy pulp, locules separating easily, firm, rather thick rind, small navel, and absence of seeds.

Texas

The commonly grown varieties of sweet oranges, along with other varieties of citrus, were brought into the lower Rio Grande Valley of Texas early in the twentieth century, but in general these are not as

well adapted to the climate as the grapefruit. The most desirable early to midseason variety of orange is the Hamlin. The trees are prolific, regular bearers under lower Rio Grande Valley conditions, maturing their fruit in October. Although the Pineapple is the most widely planted early variety, the Weslaco substation of the Texas Agricultural Experiment Station recommends that Hamlin and Joppa should replace varieties such as Pineapple, Parson Brown, and Ruby, which are characterized in Texas by the production of undersized. fruit and by erratic bearing habit (*16*). Even the desirable strains of Washington Navel are not satisfactory, being "rather erratic in their bearing habits" and producing juice "variable in flavor, often being quite insipid (devoid of acid)." A recent introduction, one of several navel oranges brought by the Department from Brazil and now under test at the Weslaco substation, is very promising. It has been named Texas Navel (fig. 12) and is being tried extensively by growers. The tree is vigorous and somewhat more productive than the strains of Washington Navel under Texas conditions. The fruit is typically navel in structure, of medium size and good quality.

The Valencia, which matures its fruit from December to January under lower Rio Grande Valley conditions, is the "most profitable commercial variety at the present time, since the trees are productive and fairly regular in bearing, but a large proportion of the fruit, which are of good quality, is undersized."

The Temple orange, which belongs to the horticultural group of high-quality hybrid fruits (tangelo oranges) and is similar to the sweet orange, is promising under Texas conditions, but the rind texture is unattractive and the tree is not hardy. In this same group the Orlando, Seminole, Minneola, and Umatilla varieties are under test.

As far as the standard varieties of sweet oranges are concerned, none is entirely satisfactory under lower Rio Grande Valley conditions.

Louisiana

In the extreme southern tip of Louisiana on the Delta of the Mississippi, south of New Orleans, in the vicinity of Buras, a type of high-quality nonnavel sweet orange of local origin has been grown for a great many years along with some navels of recent introduction. The annual output is usually about 300 cars, marketed primarily in New Orleans.

Grapefruit Improvement

The origin of the grapefruit as a horticultural citrus type is obscure. It is apparently intermediate between the large acid shaddock and the mild salad citrus type commonly referred to as the pummelo. It was brought to Florida from the West Indies and does not correspond to any type in the Orient. It was not appreciated until it was brought to the attention of the consuming public in the 1880's by enterprising Florida citrus growers. It represents a most important horticultural achievement, for it is now found on the breakfast table in either the fresh or the canned state not only in the United States but also in Europe, South Africa, and Australia.

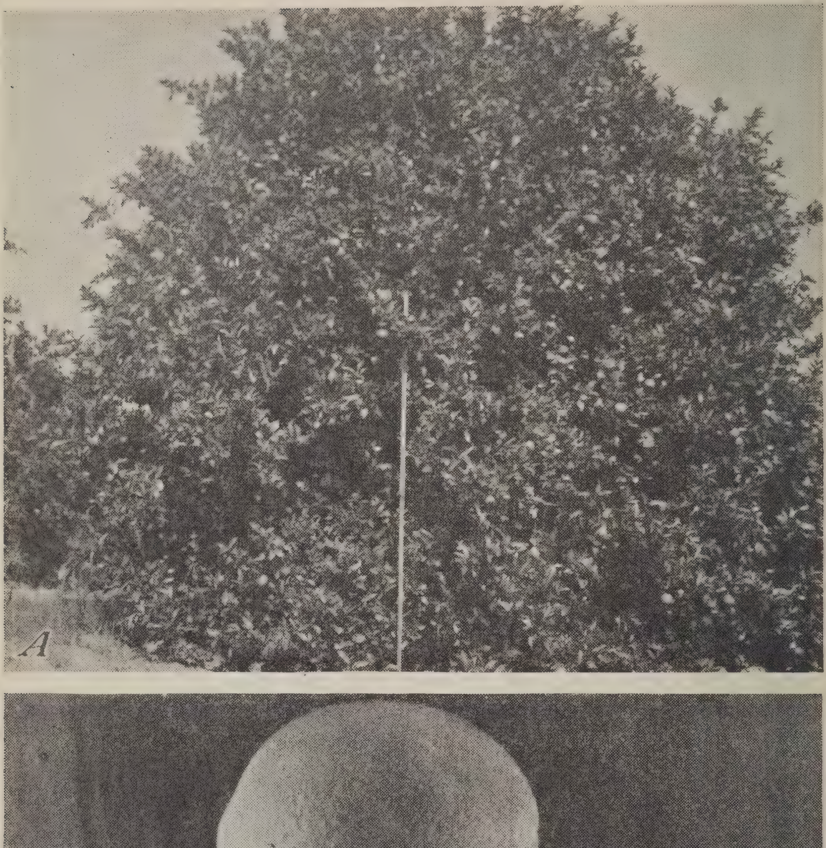

Figure 12.—See legend on opposite page.

Florida

The grapefruit industry in Florida was founded originally on seedling trees, which are very much like the Duncan variety in structure and quality and are now known as Florida Common. The original Duncan tree, over 100 years old in 1926, according to Hume (*32*), was still living in the planting known as the Snedicor Grove near Green Springs, in Pinellas County, where it originated as a seedling from a grapefruit tree grown by a Spanish settler, Don Philippe. Later reports are not available. Duncan (*14, p. 136*) stated in 1892 that Don Philippe brought grapefruit and orange seeds from Cuba 50 years previously and made his planting at Safety Harbor in "Philippe Hammock", and that the orange trees died out from neglect while the grapefruit trees remained in a thrifty condition. The variety was introduced and propagated by A. L. Duncan, of Dunedin, about 1892. It is a very superior variety. Although 17 or more main varieties were later introduced, Duncan remained the favorite among the seedy varieties. Duncan and other seedy varieties are now being top-worked to Marsh in some instances because of the demand for a seedless fruit.

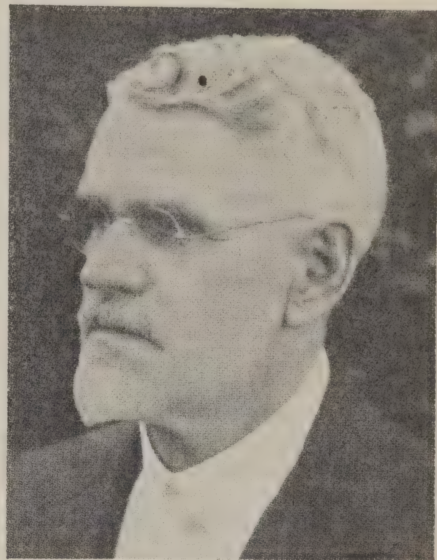

Figure 13.—Egbert N. Reasoner (1869–1926), pioneer nurseryman of Florida, active in the introduction and propagation of many subtropical fruits. He introduced Foster, Thompson, Pernambuco, and Royal grapefruit varieties and the Oneco tangerine, initiated the commercial propagation of the lychee, and was active in testing and disseminating new varieties of mangoes and avocados.

Because of its seedlessness and other desirable qualities the Marsh variety has been gradually replacing the seedy varieties in plantings within the last 15 years. This variety originated in the William Hancock grove at Socrum, near Lakeland, and was first cataloged by C. M. Marsh in the Catalogue of the Lakeland Nurseries for Fall 1896 and Spring 1897, with the statement that the parent tree was a seedling that had been a prolific bearer for 30 or 40 years. Propagation evidently began some years before, as the parent tree was killed in the freeze of 1894–95. A story receiving credence in

Figure 12.—The Texas Navel orange. *A*, Tree showing vigorous habit of this navel variety, an introduction from Brazil made by the United States Department of Agriculture in 1917 when the Washington Navel proved poorly adapted to lower Rio Grande Valley conditions. The tree has a height of 20 feet and a spread of 21 feet. *B*, Fruit of the Texas Navel orange, which resembles the standard Washington Navel in physical characteristics and quality but is more prolific under conditions in southern Texas. Fruits average 2¾ inches in diameter.

recent years that the variety originated as a broken root sprout from a common seedy type tree has been definitely disproved by the testimony of members of the Hancock family and other local residents who were thoroughly familiar with the original seedling tree (*56*).

The Marsh variety has given rise to two pink-fleshed bud mutations. A. D. Shamel has described one of these that originated near Riverside, Calif., and was brought to his attention in July 1919 by L. V. W. Brown. The mutation that occurred in Florida, in the grove belonging to W. B. Thompson near Oneco, was discovered by S. A. Collins and introduced under the name of Thompson by Reasoner Bros. (fig. 13), of Oneco, in 1924 (*55*). Both of these mutations are identical with Marsh except in flesh color. The Thompson variety, although not extensively planted in Florida, has become an important variety in the lower Rio Grande Valley of Texas.

The Foster, another pink-fleshed variety, originated as a branch mutation on a tree of the Walters grapefruit. This occurred in the Atwood Grove near Palmetto, and was first observed in the season 1906–07. It was named and introduced by Reasoner Bros. in 1914. Aside from the color, the fruit has much the same quality as the parent variety, though it is sometimes regarded as earlier maturing. The color of the pulp, as well as that of the Thompson, tends to fade as the fruit reaches full maturity.

Another seedless grapefruit, the Davis, originating from a cross between a seedling type of grapefruit and a tangerine (in the attempt by Department workers to secure a tangelo) is receiving favorable attention. In shape and size it resembles the Marsh, though it is more rounded in form, but it has the taste quality of the seedy grapefruit, with apparently less glucosidal flavor than the Marsh. Its outstanding character, however, is the fact that it has proved satisfactory for canning, the pulp remaining firm, while the Marsh tends to become soft from processing (*34*).

In the improvement of grapefruit there has been a steady trend toward the use of fewer varieties, and Marsh, largely because of its seedlessness, has become the standard for new plantings, gradually superseding the 17 or more other varieties—Aurantium, De Soto, Excelsior, Hall, Josselyn, Leonardy, Manville, May, Bowen, McCarty, McKinley, Inman, Pernambuco, Royal, Triumph, Walters, etc.

Texas

The Florida grapefruit varieties were introduced into California, Arizona, and the lower Rio Grande Valley of Texas.

The grapefruit is apparently well adapted to the lower Rio Grande Valley, and it has served as the basis of a citrus industry built up since 1910. As grown in the valley it has "a pleasing, mild flavor that has met with favor in most of the markets where the fruits have been offered for sale" (*16*).

Such varieties as Duncan, Conner, McCarty, Inman, and Walters, all seedy varieties, are grown to a limited extent for the early market, but they are at a discount after the seedless variety, Marsh, is ready for market.

The pink-fleshed varieties Foster (seedy) and Thompson (seedless) have pink flesh early in the ripening season and usually sell at a

premium. The Ruby, a local mutation from Thompson, has both pink flesh and pink rind and is receiving some attention in recent plantings.

California and Arizona

The grapefruit industry in the Southwest began after the introduction of the Marsh grapefruit in 1890; the plantings of other varieties previous to that time did not prove profitable. In the Arizona citrus districts and in the Coachella and Imperial Valleys of California, grapefruit matures fairly rapidly and is marketed in late fall and early winter; in other California grapefruit districts it does not reach full maturity until the following spring or summer.

Mandarin Improvement

In the mandarin orange group the tangerine and satsuma oranges are grown to supply special markets, primarily early in the season. The chief breeding problem is in connection with the production of high-quality early-maturing varieties.

Tangerine Orange

The only variety of tangerine orange extensively planted in Florida is the Dancy, a prolific variety that was originated as a seedling by George L. Dancy, of Buena Vista, St. Johns County, and was introduced in 1871 or 1872. This variety is of great interest, since it is the pollen parent of most of the tangelo oranges, and it imparts to the best tangelos the deep orange rind and flesh color and the aromatic and pleasing ester qualities. In Texas, although the earlier plantings are mostly Dancy, the Clementine (Algerian) is decidedly superior to this variety, as is also the Warnuco (Ponkan) under lower Rio Grande Valley conditions.

In California the Dancy is grown to a limited extent for special markets, but apparently the small size and higher acidity developed when it is grown in this section has retarded extensive planting. Recently three mandarin varieties, developed by Frost (*21*) at the Citrus Experiment Station, Riverside, have been introduced for preliminary trial. They were originated as a first-generation cross between the King orange and other mandarin oranges. In the case of the Kara, the Owari satsuma was the seed parent, and in the case of the Kinnow (fig. 14) and Wilking, the King orange served as the seed parent and the Willowleaf mandarin was the pollen parent. These varieties produce fruits of good size and excellent quality, but, as pointed out by Frost, only orchard tests can determine their ultimate value in citrus culture.

Satsuma Oranges

The satsuma orange was first introduced into Florida by George R. Hall in 1876. In the upper Gulf coast region, from western Florida to eastern Texas, it has been grown commercially since 1910, and the industry is based primarily on the Owari satsuma. Although there are apparently two or more strains of this variety, they do not differ widely. The fruit is harvested early in the season, October and November. It is desirable to harvest as early as possible for two reasons—to secure the early market before many high-grade sweet

oranges are shipped from peninsular Florida, and to remove the fruits early enough to allow for the storage of maximum food reserves in the tree before the onset of winter. In an attempt to meet this need, the Department of Agriculture imported over 50 strains of the early-maturing satsuma from Japan, and these are under test at the Gulf Coast Substation at Fairhope, Ala., in cooperation with the

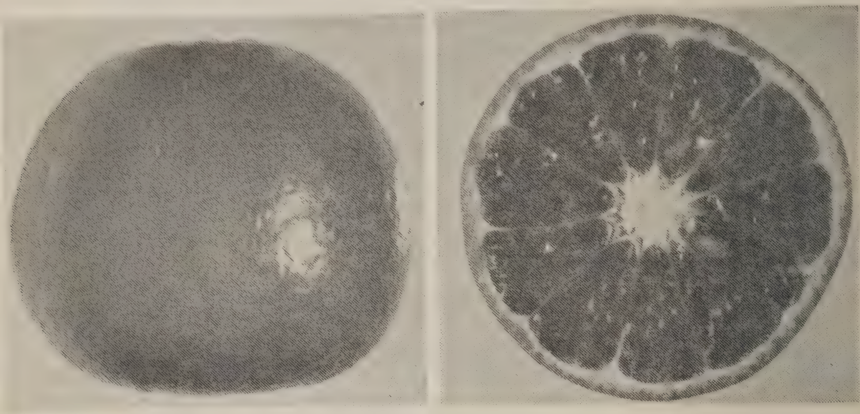

Figure 14.—The Kinnow mandarin, a hybrid of King orange and Willow leaf mandarin, the King serving as the seed parent. The fruit is excellent in appearance and flavor, remaining firm when fully ripe; desirable for local consumption but shipping quality undetermined. Fruits shown are natural size, about 4½ months after ripening. Introduced by Frost, of the California Agricultural Experiment Station.

Alabama Agricultural Experiment Station and with growers in various parts of this section. So far the Kawano variety has shown some promise, but it does not uniformly mature earlier than the Owari. Some of the other strains may prove more regular in this respect.

A selection from extra vigorous apogamic seedlings following cross-pollination of the satsuma orange with the sweet orange is promising from a commercial standpoint. The Silverhill variety, originated in this manner, has now been tested for a number of years and appears to be a superior strain of the Owari. It has shown somewhat more resistance to cold than the other satsuma varieties, but the evidence is not conclusive.

Improvement of Acid Citrus Fruits

The chief center of lemon culture is in California, and lime production is confined primarily to Florida.

Florida

The introduction of the citrus scab proved a serious drawback to lemon culture in Florida. There is also great difficulty in properly curing lemons in the humid summer climate. In 1931 the Department introduced the Perrine lemon (fig. 15), a hybrid between the Genoa lemon and the Mexican or Key lime. It is highly resistant to citrus scab and anthracnose and has given a new impetus to the industry.

The Perrine lemon is a rapid-growing, vigorous, and productive tree. The fruits are borne singly or in clusters and are of medium size, with a high acid percentage, ranging from 6.2 to 7.2 percent, ranking with standard commercial varieties in this respect (*71*, *80*).

The Meyer lemon, an introduction from China named for the introducer, the late Frank N. Meyer, famous plant explorer for the Department of Agriculture, is chiefly noteworthy for its frost resistance.

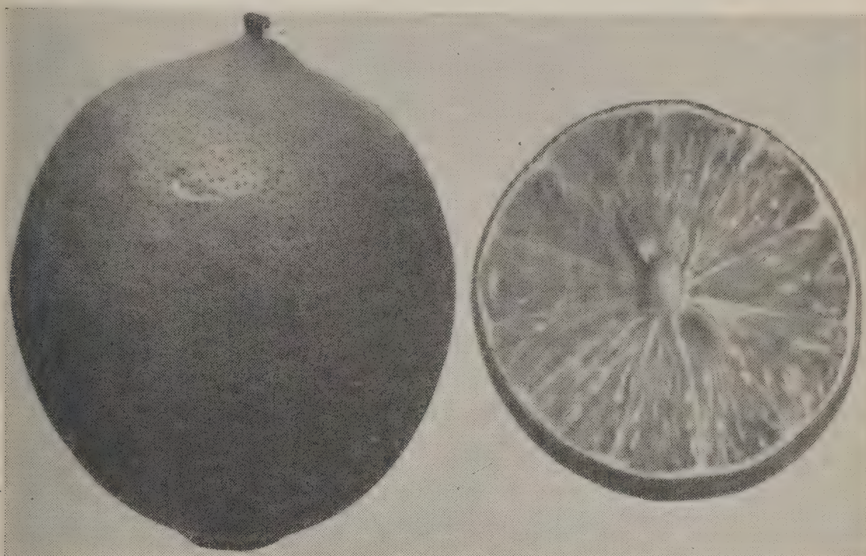

Figure 15.—Typical fruits of Perrine lemon, a hybrid between the lemon and the lime; remarkable for its resistance to scab and anthracnose, vigor of growth, and heavy bearing. Resembles the true lemon in shape, size, and acid content. Introduced by the United States Department of Agriculture.

Its low acid content (4.3 to 4.8 percent), large size, and round shape preclude its general popularity as a commercial lemon, though it is well suited to local needs where true lemons have proved too tender

The Key, Mexican, or West Indian lime has long been cultivated primarily on the keys, but recently the industry has declined because of hurricane damage. The Tahiti (also called Persian or Bearss) lime has recently been planted to a considerable extent in Dade County and the southern ridge section. It has high quality, and in addition the aromatic properties of the rind are highly valued by the consumer. The Lakeland and Eustis limes, hybrids of lime and kumquat, introduced by the Department, although of high juice quality, are of small size and have a thin rind, which may prove disadvantageous for storing and shipping.

California

In the early development of the industry a large number of European varieties of lemon were grown and also many seedlings were raised, most of which were not promising. The present plantings are practically limited to Eureka and Lisbon. The former originated from a seed planted in 1870 by C. R. Workmen in Los Angeles. The Lisbon

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variety originated in Europe. Shamel and coworkers (*64*) state that the Lisbon lemon was introduced into California in a number of importations, the first of which was made as budded trees in 1874 and 1875 from Australia. It has been pointed out that the advantages of the Eureka are its comparative freedom from thorns, its tendency toward early bearing, and its prolific bearing qualities. The tendency to bear fruit on the tips of the branches and the inclination to grow long canes with but few laterals and to drop its leaves on the long canes or branches, leaving the limbs and fruit too much exposed to the hot rays of the sun, are disadvantages.

The Lisbon has heavy foliage, which protects the fruit from sunburn, and the fruit is borne uniformly throughout the tree. This variety has a tendency to bear one large crop maturing in winter, with only a small amount of summer fruit.

MINOR CITRUS FRUITS

In the United States the pummelo, citron, kumquat, and sour orange are not grown to any appreciable extent for their fruits. Of these minor citrus fruits the pummelo is the most promising. The citron is grown mainly for exhibition purposes, although a beginning has been made in California with preserving it on a commercial scale. The sour orange is grown as an important marmalade fruit in some other citrus-producing countries, notably in Spain.

The pummelo in its better varieties is a most delicious salad citrus. The juice does not possess the sprightly acid and naringin (bitter) properties of the grapefruit, but when the juice sacs are served as a salad the inimitable flavor is relished by all who have had the good fortune to sample them. In times past only the sour shaddock was known in the citrus-producing districts, but since 1915 the Department of Agriculture, through its collaborator, G. Weidman Groff, in China, has introduced an important collection of pummelos. These are not as yet well known but are being distributed to those interested in the culture of the fruit. One of the outstanding varieties is named Siam. Reference to this collection will be found in table 5.

The Department has also imported a valuable collection of citron varieties, including practically all of the important ones. Corsican, the chief variety of commerce, was one of the first citrus introductions made by Fairchild, who was for many years in charge of the plant introduction work of the Department.

Kumquats were introduced into Europe as recently as 1846 by Robert Fortune. Importations into the United States were made by Taber in 1885 and Reasoner in 1885 and 1890. The varieties Nagami (oval) and Marumi (round) were first introduced, and later the Meiwa or sweet kumquat. The Nagami predominates in all plantings made thus far. About 1910 the Department introduced the Hong Kong or wild kumquat, which produces very small round fruits and is of interest from the breeding standpoint in that it has the double haploid chromosome complement. (See the later section on cytology in this article.)

The Department has introduced a superior variety of sour orange named Oklawaha. It originated as an apogamic seedling when pollen of the shaddock (sour pummelo) was used to pollinate the sour orange.

In habit the tree appears as a vigorous sour orange. The fruit is similar to the ordinary sour orange but averages larger in size, 3 to 4 inches in diameter, and it is superior to the ordinary seedling sour oranges as a marmalade variety.

CITRUS BUD SELECTION

With the general acceptance of De Vries' mutation theory (1901), the improvement of varieties by the selection of bud mutations soon became a recognized mode of procedure in plant breeding. Conversely, the elimination of inferior bud mutations became of equal or even greater importance in many clones especially subject to mutations.

That the Washington Navel orange is subject to bud mutation was recognized at an early date, and by 1910 the problem was so serious that at the California State Fruit Growers Convention of that year Coit (*10*) proposed to "keep individual tree records for 2 years and these trees with records to be offered nurserymen for propagation as pedigreed trees." At the same meeting Coit, in discussing the application of the De Vries mutation theory to the problem, said:

> If you go out into the average navel orchard to select a dozen perfect navel oranges true to old standards, you will be surprised at the amount of searching necessary. * * * It is my belief that by far the greatest part of the divergence is attributable to mutation * * *.

He added that propagators—

> must be quick to see and cut out all branches sporting toward poor types. In the second place, we must be exceedingly careful in cutting budwood. * * * Select buds from those branches which produce your ideal of the navel orange.

The problem was so serious that the Department of Agriculture detailed A. D. Shamel to study it in 1909, and he began his work in cooperation with the California Citrus Experiment Station at Riverside and with citrus growers. In his first report entitled "Bud Selection in Citrus Fruits", given at the California State Fruit Growers Convention at San Bernardino, March 8, 1911, Shamel set forth the problem clearly. His work began with the Washington Navel and was extended to include other sweet oranges, the lemon and grapefruit types, as well as other crop plants.

Over a period of 27 years the work of Shamel and his coworkers (*57*, *58*, *59*, *60*, *61*, *62*, *63*, *64*) has been characterized by consistent, painstaking research, which has included a study of the source of strains originating as bud mutations and unintentionally propagated by nurserymen and growers. This was followed by efforts to eliminate the inferior trees in established plantings by top-working with carefully selected buds. Further efforts were made to avoid the propagation of undesirable strains arising from bud mutations by systematic selection on the basis of individual plant performance and an intimate knowledge of the plants. Finally, a systematic search was made in cooperation with growers for superior plants originating from commercially valuable bud mutations, and these were tested in progeny plantings to single out the ones inherently superior to the parent forms for utilization by the industries concerned.

In the case of Washington Navel orange it has been shown (*61, p. 67*) on the basis of individual performance records made in several California groves since 1909 that—

these groves consist of at least 20 strains of commercial importance with five or more others of less economic consequence. The trees of each of these strains have fruit or vegetative characteristics, or both, which serve to distinguish them from all other trees of the variety.

About 25 per cent of the total number of trees studied in the original orchards in which these investigations have been conducted were found to be of undesirable strains having consistently low yields, or bearing fruits of poor quality, or both, such as those of the Australian, Unproductive, Corrugated, Pear-Shape, Sheepnose, Flattened, Dry, and other inferior strains.

The extent of the commercial use of superior strains selected for the production of more uniformly good fruit is indicated by the sale of selected buds by the Fruit Growers Supply Co. for the period 1917–35. These data, given below, include only a part of the supplies of such buds used by nurserymen and growers—probably not more than 50 percent; but because they are conservative they will the better convey some idea of the value of this kind of work.

Name of strain	*Number of buds sold*
Superior strain of the Washington Navel orange	1, 402, 950
Superior strain of the Valencia orange	2, 338, 004
Superior strain of the Marsh grapefruit	1, 262, 757
Superior strain of the Eureka lemon	766, 950
Superior strain of the Lisbon lemon	86, 215
Superior strains of miscellaneous citrus varieties	66, 886

Two special citrus strains originating as bud mutations, the Robertson Navel orange in 1925 and the Dawn grapefruit in 1929, are now being introduced, and the indications are that they will be widely grown in certain citrus districts of California and Arizona. In the Robertson Navel orange strain the fruits are resistant to June drop on account of their very rapid early growth. They mature about 1 month earlier than those of the Washington Navel orange under comparable conditions, and the trees are more productive than the normal Washington Navel. Otherwise the mature fruits of the Robertson strain and those of the parent variety are very similar and cannot be distinguished even by those who have grown and studied them.

The Dawn is a strain of the Marsh grapefruit in which the fruits mature about 1 month earlier than those of the parent variety, and the trees are unusually productive. Otherwise the Dawn and the Marsh trees and fruits have similar characteristics. The indications are that this strain will be a particularly valuable one for growing in the desert grapefruit-growing districts.

Many other citrus bud mutations are under test in cooperation with growers in California and Arizona, and some of these promise to be of commercial importance in the near future.

In the history of subtropical fruit breeding the work of Shamel, his coworkers, and the California Agricultural Experiment Station cooperators is inspiring. It is characterized by consistent, painstaking research and unwavering purpose. In the earlier years, although the work was fully appreciated by the growers in the region, scientific workers elsewhere did not give entire credence to the remarkable evidence uncovered. As time went on, Shamel and his coworkers answered their critics by applying statistical methods to the data, which gave convincing proof of the conclusions. Later, numerous bud mutations were also discovered in other fruit types, including apple, and by the time the work was no longer challenged the results

achieved stood out as monumental in this particular field of research. The practical benefits to the industry can be gaged by the millions of selected buds that have been used by the citrus growers in California and elsewhere. A summary of the bud mutations and strains isolated by Shamel and his coworkers is to be found in table 8.

In Florida a bud-selection project has been in progress since 1921. The mode of procedure differs somewhat from that followed in California and was developed cooperatively by the Florida Agricultural Experiment Station and the Department of Agriculture. At the Lake Alfred Citrus Experiment Station a progeny grove has served as the basis of variety improvement. In this progeny grove standard varieties of oranges and grapefruit are represented by rows budded from parent trees of known production, several such selected parents being included for each variety. Production records have been kept, and a detailed study of fruit characteristics has been made as the basis for reselection among the original progenies. For purposes of comparison a few offtype progenies have been included, which have served well to illustrate the importance of careful bud selection in nursery propagation. Growers and nurserymen have gradually come to realize the value of such true-to-type budwood, which has been made available through the experiment station for several seasons past at a cost not greatly in advance of common commercial rates.

Other bud mutations of value to the citrus industry are Foster, Thompson, Ruby, and Davis grapefruit (described above), Silverhill satsuma orange, and Oklawaha sour orange, the three latter being seedling or nucellar mutations.

ROOTSTOCKS

A NUMBER of citrus types and varieties are of major importance because of their value as rootstocks for the varieties grown commercially. In the early development of the citrus industry, especially in Florida, seedling citrus trees were extensively planted, but gradually this practice was discontinued, as it was realized that certain rootstocks were better adapted to the soil conditions. This advance was made by the expensive trial-and-error method, and the stage reached by the 1890's was recorded by Van Deman (*81*). Planned experiments with rootstocks have been relatively rare. In California, Mills (*46*) has reported results secured at the experiment station at Pomona, and Bonns and Mertz (*3*) described the experiments carried out at the Citrus Experiment Station at Riverside. The important work of Webber (*85*) at the citrus station is an illuminating piece of research into the seedling variation of the types commonly used as rootstocks. Unfortunately, the work of Taber (fig. 16) quoted by Hume (*31, pp. 209–218*) at the Glen St. Mary Nursery in Florida was discontinued too soon. Traub and Friend (*77*) have reported on preliminary experiments in the lower Rio Grande Valley of Texas. Akenhead, Feilden, and Hatton (*1*) have recently summarized the investigation on citrus rootstocks.

As indicated, the horticultural utilization of rootstock types is based at present mainly on the knowledge accumulated through many years of trial and error. The final results are very valuable, though they were secured at great economic expense. The entire field has not been exhaustively explored.

In general it may be stated that in Florida, as pointed out by Camp (*4*), the rootstock problem is more complex than in the lower Rio Grande Valley of Texas, in California, or in Arizona.

Three major considerations are necessary in the choice of suitable rootstock—congeniality between stock and scion, resistance to diseases, and adaptation to the soil and climatic conditions. Rootstocks have been tested over a considerable period by commercial growers, and at the present time only three are extensively used—sour orange, rough lemon, and the trifoliate orange. The Cleopatra mandarin has recently received some attention as a rootstock. In Florida, trees on grapefruit stock grow vigorously in the early stages but usually prove to be shy bearers and show decline after a number of years. Sweet orange is susceptible to foot rot, and both grapefruit and sweet orange are less cold-resistant than sour orange. The commercial lemon is susceptible to diseases, and trees on it are short-lived. The citrange has been tried as a substitute rootstock in place of the trifoliate orange for the satsuma orange, but recent observations have shown that the citrange is not reliable in the Gulf coast region, since it is evergreen and does not go dormant sufficiently during the winter season. This has resulted in the loss of the scion variety in some seasons.

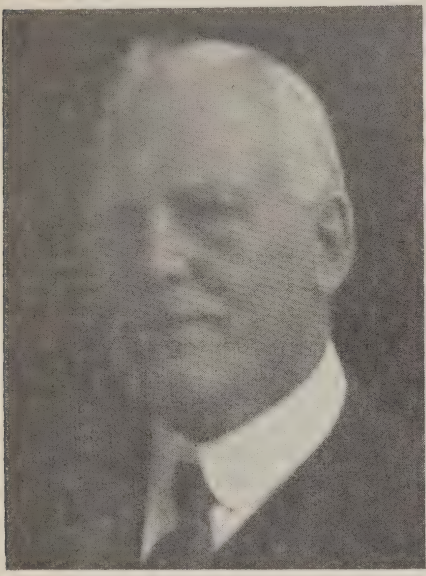

Figure 16.—George Lindley Taber (1854–1929), pioneer nurseryman of Florida, who demonstrated the limitation of the satsuma orange to trifoliate orange stock, founding a new industry; introduced Duncan grapefruit, Lue Gim Gong sweet orange, and varieties of persimmons, and cooperated with the United States Department of Agriculture in the production of early citrus hybrids.

The sour orange is a useful stock in all citrus-growing regions except South Africa, where all attempts to use it so far have failed. It is compatible with most citrus types except satsuma, kumquat, and lime. In California, lemon trees on this stock may show decline after 10 to 20 years, which has been attributed to the stock. For this reason many of the recent lemon plantings in California have been budded on the sweet orange. The sour orange is highly resistant to cold and to root and crown bark diseases, but highly susceptible to citrus scab. Roots are deeply penetrating, and the stock is well adapted to clay subsoils and wet or heavy soils. In Florida it is successful on moist hammock as well as on moist flatwoods soils and on the heavier soil types in general. In California, Arizona, and the lower Rio Grande Valley of Texas it tolerates irrigation conditions. This, together with its adaptability to southwestern conditions, has made it the rootstock almost universally used in these regions. Its

main drawback is its relatively slower growth on light soils as compared with rough lemon, but on heavier soils the rate of growth is satisfactory.

The rough lemon (*Citrus limonia*) makes a satisfactory growth even on very light and sandy soils. This makes it valuable in certain sections of peninsular Florida. It is highly susceptible to citrus scab and susceptible to foot rot and other root and crown diseases, but this apparent handicap is minimized, for on sandy soils these diseases are less troublesome than on the heavier ones. It is extensively used as a rootstock for citrus on soil types not suitable for sour orange in Florida. It is not well adapted for use with the satsuma orange, producing coarse, raggy fruit.

The trifoliate orange was once recommended as a rootstock for citrus in the lower Rio Grande Valley of Texas (*48*), chiefly on account of cold resistance; but it proved susceptible to foot rot and cotton root rot and was later discarded in favor of the sour orange (*77*). In the upper Gulf coast region it is universally used as a root stock, since it is deciduous and goes more dormant during the winter season than evergreen citrus types. It is the hardiest of the citrus types.

Recently the Cleopatra mandarin has been recommended as a rootstock in place of rough lemon, chiefly on the basis that it is more cold-resistant than the rough lemon and tends to produce better textured fruit, holding fruit later in the season in good condition. It is immune to scab and resistant to gummosis. However, experimental work has not been carried out extensively enough to warrant unqualified recommendation.

It has already been pointed out that most citrus seeds produce more than one seedling, and that any extra seedlings not of seminal origin are produced by budding from the mother plant tissue. On the surface it would appear that this is an ideal condition from the standpoint of seedling rootstock production, since it would give a large percentage of plants like the original stock, and this is true in the main. Webber (*85*) and Frost (*20*) have shown, however, that variations may occur even among such nucellar seedlings. Frost points out the influence of mutations in this connection. The work of Webber is of special interest. His experiments, which were started in 1914, show that—

> citrus seedlings of the species and varieties most commonly used as rootstocks exhibit a wide range of variation. In any lot of seedlings grown from seed of the same variety and from the same source, the great majority usually are of the same general type, but from 5 to 40 per cent of them are highly variable types which apparently differ in genetic constitution from the prevailing type and from each other.

These variants may include both apogamic and seminal seedlings. They are usually small and lacking in vigor and when used as stocks induce dwarfing of the tree. His experiments show that small seedlings and "small budlings tend to produce small, low-yielding orchard trees; and that large seedlings and large budlings tend to produce comparatively large, high-yielding orchard trees." In order to secure the desired uniformity in orchard trees, Webber advises "a moderate culling of small seedlings at the seed bed, followed by a careful roguing and destruction of all variants and small seedlings in the nursery just prior to the budding."

CITRUS IMPROVEMENT IN FOREIGN COUNTRIES

This section, like the similar sections in connection with other subtropical fruit crops, is based almost entirely on replies received to the questionnaire dealing with the Cooperative Survey of Plant and Animal Improvement. The information received mainly concerns the present and future objectives of breeders.

Mexico

Citrus studies are carried on at experiment stations of Montemorelos, Nuevo Leon; El Yaqui, Sonora; and Emporio Macuspana, Tabasco. Infestation of fruit by the orange maggot, *Anastrepha ludens* Loew, constitutes the most serious problem. Methods of attack are being studied, but without practical results thus far.

South America

At the Instituto Agronomico do Estado de São Paulo in Brazil, work with citrus under the direction of C. A. Kruge, head of the genetics department, is being confined primarily to the improvement of varieties by bud selection and to the improvement of the sour orange rootstock by making extensive progeny tests. The disease resistance of rootstocks is also being studied.

In Chile no breeding work with subtropical fruits is under way at the experiment stations, but Salvador Ezquierdo at Santiago has for many years introduced varieties of citrus, avocados, etc., to test their adaptability to Chilean conditions.

At the Estacion Experimental de Concordia, Argentine Republic, Signor Ruben Bence Pieres, director of the station, is conducting experiments with citrus which concern the selection of sour orange seedlings, with a view to obtaining strong, vigorous, fast-growing plants. A naturally occurring hybrid mandarin named Malvasio, with a large fruit, fine rind color, excellent quality, and late maturity, is being tested and shows promise of commercial value. The main introduced varieties, which have been selected from a large number and are being extensively cultivated, are the Marsh and Qurian grapefruit and the Valencia and Lue (Lue Gim Gong) sweet oranges. The cultivated area of grapefruit and sweet oranges approximates 5,000 acres, with about half devoted to each type. The main problem that confronts the citrus industry is the ravages of foot rot. Work is in progress for the selection of resistant stocks, as indicated above.

Europe and North Africa

At the Estacion Naranjera de Levante at Burjasot, Valencia, Spain, work has been carried on in sweet orange breeding since 1927 under the direction of Manuel Herero. The work has been confined mainly to selection from open-pollinated seedlings of Washington Navel. Two improved varieties have been selected, one round and the other oval in form. These are being cultivated to the extent of about 375 acres. Hybridization work was begun in 1932 and is being carried on to the second generation after crossing. The crosses made are those between the sweet orange and the mandarin.

A. Biraghi, pathologist, Italian Department of Agriculture, Rome, reports that the chief problem with citrus culture in Sicily is in con-

nection with the disease mal secco, chiefly affecting lemons. Attempts are being made to breed varieties resistant to this disease. Two resistant lemon varieties of unknown origin and not desirable for quality have been found locally, and promising varieties have been imported from India (*2*) and the United States for use in breeding experiments.

At the Superior School of Agriculture, Laboratory of Horticulture, Athens, Greece, P. Th. Anagnostopoulos has gathered together a collection of citrus species for selection and breeding work.

In Morocco, under the leadership of F. Lacarelle, director, and Ch. Miedzyrzecki, geneticist, Experimentation Fruitière et Maraichère, Rabat, citrus fruit improvement is being studied through several methods: (1) Bud selection, (2) hybridization to secure improved varieties and varieties resistant to disease, and (3) selection of stocks. The varieties receiving the most attention are Washington Navel, Valencia Late, and Clementine. A special study of the seed content of the Clementine led to the conclusion that seed production is largely dependent on the proximity of other varieties, especially of mandarin oranges, to furnish pollen to the flowers of the Clementine, self-fertilized flowers being almost seedless (*38*, *39*).

Asia and Malaya

At the Jewish Agency Agricultural Research Station, Rehoboth, Palestine, the experimental work was started by J. D. Oppenheim and is now being continued by Ch. Oppenheimer. The work is confined primarily to improvement by bud selection, which was begun in 1934, and by hybridization, begun in 1933. The first-generation hybrids have not reached fruiting stage. The hybrids are from crosses of the Jaffa orange with other early and late varieties, of the blood orange with the tangerine, and of the sour orange with the sweet lime. The station has gathered together a collection of about 70 citrus varieties.

Theoretical studies are under way on the inheritance of peel thickness in citrus and on the effect of pollination on number of seeds.

At the Imperial Horticultural Experiment Station at Okitsu, Japan, T. Tanakawa is carrying on investigations in bud variation in early- and late-maturing satsuma oranges. Sixty-one late strains and 42 early strains are being tried out. The work was started in 1925 and is still in progress. Citrus hybridization work was begun in 1909.

Tyozaburo Tanaka, professor of horticulture at the Taihoku Imperial University, Taiwan, Japan, is engaged in citrus breeding. Kimijiro Noro, pomologist at the Shizuoka (Japan) Agricultural Experiment Station, has made a collection of 80 bud mutations of the satsuma orange.

At the Department of Horticulture, Lingnan University, Canton, China, G. Weidman Groff, professor of horticulture, and Pui-Man Lei, Qu-Nin Shiu, and A. N. Benemerito, pomologists, have gathered together a comprehensive citrus collection for use in the selection of desirable types of citrus and citrus relatives, particularly from the south China area, with numerous introductions from abroad. Some of the systematic work on this collection has been carried out in collaboration with the United States Department of Agriculture.

R. D. Fordham, deputy director of gardens, United Provinces, Saharanpur, India, reports that citrus rootstock trials are under way, including Khatta (Karna lime), *Citrus limonia*, Sylhet, Bijori, Sadaphal, Jamberi, Bilhari, Galgal, Sweet Galgal, Turanj, and sweet lime.

B. Nazareth, superintendent, Modibag Garden, College of Agriculture, Poona, India, reports that studies of mutations occurring in the principal citrus varieties, Santra Mosambi and Ladoo, have been made, and many well-marked sporting forms have been recognized. Breeding work thus far has been confined to mass selection both for rootstocks and for scion varieties. Collections of scion and rootstock varieties are being made to initiate systematic breeding of fruit crops adapted to different soil and climatic conditions. Attempts at hybridization made in 1912, 1914, and 1918 gave negative results. Polyembryony in citrus has been studied, showing varying percentages, from none in the pummelo to 60 percent in the Ladoo orange. The Marsh (seedless) grapefruit has been introduced for culture in the Bombay region.

South and Central Africa

The Department of Agriculture, Zanzibar, East Africa, is studying local and imported varieties of citrus in a series of plots. This work is being carried out by A. Q. Findley, director.

Australia and New Zealand

At the Department of Agriculture and Stock, Brisbane, Queensland, bud selection of citrus has been practiced for many years and Government certified budwood is available for nurserymen. The chief sweet orange varieties grown are Washington Navel, Valencia, Jaffa, Sabina, and Joppa. The lemon varieties are Lisbon and Villa Franca. The mandarin varieties are Beauty of Glenn Retreat, Emperor of Canton, Scarlet, and Fewtrel Early. The grapefruit variety is Marsh, and Seville sour orange is grown for marmalade. Sour orange and rough lemon rootstocks are used for citrus except that mandarin is grown on mandarin.

At the Department of Agriculture, Division of Horticulture, Melbourne, Victoria, J. M. Ward, superintendent of horticulture, has carried on work in bud selection since 1931, and up to the present one variety has been propagated—a thin-skinned early navel orange, which has not as yet been named. The department also supplies buds of selected strains of the Washington Navel and Valencia to growers and nurserymen. No work in hybridization has yet been carried out.

At the Department of Agriculture, Division of Horticulture, Wellington, New Zealand, J. A. Campbell, director, has gathered together a representative collection of citrus species and varieties for intensive study.

H. Wenholz, director of plant breeding, Department of Agriculture, New South Wales, Australia, reports that citrus breeding is being carried on at the Grafton Experiment Farm and the Hawkesbury Agricultural College with the object of producing "a late hanging navel orange" and a late Valencia of fine texture. A cross has been made between Valencia and a very fine-textured seedling variety.

TECHNICAL PROBLEMS AND RESULTS IN CITRUS BREEDING[4]

Progress in genetic research has been greatly retarded on account of the common occurrence of polyembryony in most citrus types, which makes it necessary to grow to the fruiting stage large numbers of

Figure 17.—Embryo development and "nucellar embryony" in *Citrus* and *Poncirus*, after Osawa (*50*): Nos. 72, 80–85, trifoliate orange; 73–76, satsuma orange; 77, Washington Navel orange. (Original magnifications changed to conform to present reduction.) 72, Two-nucleated embryo sac, X 570. 73, An ovule showing embryo sac, nucellus, and inner integument, X 175. 74, Details of embryo sac of no. 73, with four nuclei, X 570. 75, Embryo sac with eight nuclei, X 570. 76, A mature embryo sac with egg apparatus, polar nuclei, and antipodal cells, X 570. 77, The same, X 570. 80, Micropylar portion of an embryo sac, showing fertilized eggs, pollen tube, and endosperm nuclei, especially some large nucellar cells containing large nucleus and much cytoplasm, X 175. 81, The same, X 265. 82, Micropylar portion of an embryo sac showing two-celled embryo and endosperm nuclei, X 175. 83, An older ovule, showing embryo sac, embryo, endosperm nuclei, nucellus, and integuments, X 20. 84, Upper portion of embryo sac of no. 83 more magnified, showing six-celled embryo, endosperm nuclei, and nucellus, X 175. 85, Upper portion of an embryo sac, showing polyembryony, X 370.

seedlings that have arisen asexually. That this section is not more complete is due in the main to this one cause. Even the grouping of citrus species (*68*) is complicated by this condition.

[4] The following sections are written primarily for students and others professionally interested in genetics or breeding.

Cytological Basis for Citrus Genetics

A study of the chromosome numbers and chromosome behavior in citrus is basic to a consideration of citrus genetics. According to Frost (*20*), it may be assumed that bud-variation types originate primarily either as gene (point) mutations or as chromosomal aberrations, and an understanding of these fundamental facts may also throw some light on the great variability of F_1 hybrids between species.

Figure 18.—Howard B. Frost, associate plant breeder, California Agricultural Experiment Station, since 1912, has made important contributions to the cytology and genetics of citrus and is the originator of the Kara, Kinnow, and Wilking mandarins and the Trovita sweet orange.

Strasburger (*66*) determined the haploid chromosome number as 8 in the sweet orange (*Citrus sinensis*), the sour or bigarade orange (*C. aurantium*), and the citron (*C. medica*). Osawa (*50*) reported that the haploid chromosome number in the satsuma orange (*C. nobilis* var. *deliciosa*) was probably 8 (fig. 17).

In 1924–25 both Frost (fig. 18), at the Citrus Experiment Station, Riverside, Calif., and Longley, of the Department of Agriculture, reported important work o nthe cytology of citrus. Frost (*18*) determined the chromosome numbers in two varieties of sweet orange (*Citrus sinensis*) and one variety of grapefruit (*C. grandis*), and in each case the haploid number was 9. He observed neither polyspory nor polycary.

Longley (*45*) made chromosome counts in 24 citrus species and citrus relatives and verified the basic chromosome number of citrus as 9, but he also found 1 tetraploid species, the Hong Kong kumquat (*Fortunella hindsii* (Champ.) Swingle). He observed both polyspory and polycary in many forms. He states that "irregularities in chromosome pairing at diakinesis and in their distribution at meiosis were frequently noticed. The outcome of such irregularities was the presence of tetrads containing more than the expected four pollen grains." In grapefruit, limes, and limequats polyspory was often observed. He points out that there may be "a relation between irregular chromosome numbers and the production of citrus with supernumerary chromosomes." According to Longley, two factors, however, may hinder the spontaneous appearance of such polyploid forms—the possibility that only sex cells with 9 chromosomes are viable, and the infrequent use of seeds as a means of propagation. However, in the early history of citrus culture, seedlings were commonly used in planting groves, and the disappearance of polyploid forms is apparently because they are of little or no value in horticul-

ture, as Frost points put. Longley emphasizes the possible value of the tetraploid *Fortunella hindsii* in hybridizing with closely related diploid forms to increase the chances of obtaining forms with unusual chromosome complexes.

Later, in 1925, Frost (*19*) reported on the discovery of certain "thick-leaved" apogamic seedlings of sweet orange (*Citrus sinensis*) and lemon (*C. limonia*) which proved to be tetraploids. He had observed such types to the extent of several percent of the total progeny in some cases in 12 horticultural varieties of citrus, representing 4 species, and in 2 botanical varieties, and he points out that they also may prove to be tetraploids.

Figure 19.—Herbert J. Webber, pioneer worker in breeding citrus and other crops; United States Department of Agriculture, 1892–1907; Cornell University, 1907–12; California Agricultural Experiment Station, since 1913. He has carried on important work on rootstock variation as influenced by polyembryony.

As to the cause of these forms, Frost postulated the possibility of "islands" of tetraploid tissue in the parent trees, so that not all tetraploid seedlings represent distinct doubling of chromosome number. Against this view he found that the thick-leaved forms have not been found in mature trees by Shamel and his coworkers, and stated that this might be due to "the slower growth of tetraploid cells which might keep them from multiplying sufficiently to dominate the apical meristem, rather than to failure of tetraploidy to originate outside the nucellus." He further supported the hypothesis by citing the fact that in many cases a thick-leaved seedling has developed from a seed giving two or more nonhybrids, and in such cases the other apogamic seedlings from the same seed have almost always been normals.

In connection with these thick-leaved forms, Frost pointed out that they have not given promise of direct horticultural value, but they may be an aid in producing triploids or modified triploids by crossing with ordinary diploid forms, and that triploids would probably be practically seedless.

In 1926 Longley (*45*) reported his findings with reference to a triploid trigeneric hybrid, produced by Swingle and coworkers of the Department of Agriculture. This is a cross of the limequat (*Fortunella margarita* Swingle × *Citrus aurantifolia*) with *Fortunella hindsii*. Longley found 13 bivalent and a single univalent chromosome as the reduced number, and he found indications of only slight irregularity in chromosome distribution during meiosis in the triploid plant.

These findings led him to believe that triploids may be produced by appropriate crosses, and that in the case just cited or similar crosses there is a possibility of producing a seedless kumquat. More recently Longley[5] has found a second triploid, a sister hybrid of the first triploid found. Since most triploid plants are sterile, such crosses, it is hoped, may lead to developing seedless fruits. Longley later (April 1928) found an individual of *Triphasia trifolia* P. Wilson having 18 chromosomes.[5]

Polyembryony

In 1719 Leeuwenhoek noticed two embryos in orange seed, but it was not until 1878 that Strasburger (*65*) explained the true nature of the phenomenon of polyembryony in citrus as sporophytic budding from nucellar tissue. Frost (*19*) in 1925 found that in a minor portion of nucellar embryos—less than 1 percent—two hybrids were produced from one seed. Instances have been noted of three and even four—only two cases of the latter—apparently true hybrids produced from a single seed.[6] In one instance (lemon × trifoliate orange) out of 782 seeds, 16 produced 2 hybrids from 1 seed, with 1 producing 3 and 1 producing 4 hybrids, which is slightly more than 2 percent of "doubling."

Webber (*83*) (fig. 19), Frost (*20*), Toxopeus (*74*), and Torres (*73*) have shown that citrus types vary widely in the percentage of nucellar embryos produced (fig. 17). In a recent study made by Torres in the Philippine Islands, based on 50-seed samples, only the pummelo type did not exhibit polyembryony (table 2).

Table 2.—*Polyembryony in citrus in the Philippine Islands*

Citrus type	Average embryos per seed (range within type)	Embryos per seed (range—minimum and maximum)	Citrus type	Average embryos per seed (range within type)	Embryos per seed (range—minimum and maximum)
	Number	*Number*		*Number*	*Number*
Pummelo	1.0	----------	Sour orange	1.00 to 1.18±0.18	1 to 3
Grapefruit	1.16±0.23 to 2.86±0.89	1 to 6	Lime	1.0 to 1.20± .16	1 to 2
Sweet orange	1.32± .002 to 4.88±1.12	1 to 12	Tangelo	1.92± .45 to 2.32± .42	1 to 4
Citrus nobilis	1.02± .07 to 2.72± .44	1 to 6	Calamondin	5.32± .88	1 to 10
Lemon	1.30± .28 to 2.90± .88	1 to 6			

After summing up the evidence with reference to the effect of pollination on polyembryony, Frost (*20*) stated that it appears "very probable that citrus seeds do not develop without pollination, although seedless fruits sometimes develop without pollination even in varieties normally seedy." This would indicate that nucellar budding, which produces apogamic embryos, is at least very largely dependent on some growth stimulus due to the fertilized egg, as suggested by Strasburger (*66*) and Webber (*84*).

Frost (*20*) has shown that in interspecific crosses there is a negative correlation between the total number of seedlings and the percentage of hybrid seedlings, which shows the possible effect of competition among the embryos within the seed. During such developmental

[5] Unpublished work.
[6] Unpublished results of Swingle's crosses in 1909.

selection acting within the soma of the parent, the fertilized egg may be crowded out by the apogamic embryos, depending on the number of apogamic embryos that start and on the position and relative age and vigor of the two classes of embryos. Evidence as to selective elimination during germination was secured by noting the difference between the number of dissected embryos and the germination percentage in similar lots. During germination, survival may be determined by the "difference in size, vigor, position, morphological completeness, and susceptibility to infection." It was also noted that albinism causes the early death of many seedlings from some parents.

The variation in the number of nucellar embryos produced within a variety, and the possible effect of environmental conditions on such variation, led Traub (*76*) in 1936 to offer the hypothesis, based on preliminary experiments, that the number of nucellar embryos produced might be artificially varied by difference in food supply. If the preliminary results can be firmly established by experiments now in progress, an effective method for use in breeding work would be provided.

Swingle (*69*) postulated that citrus varieties propagated as clones are subject to senescence with age, and he cited the supposed disappearance or reduction in size of spines in well-established clones as one of the clearest indications of such senescence. He claimed that such clones might be at least partly rejuvenated, that is, become more spiny and vigorous, for instance, when seedlings from nucellar embryos were used as a method of establishing a new clone. This supposed nutritional effect of the embryo sac on the nucellar embryo developed within he named the "new-life" or "neophyosis" hypothesis.

However, there are no facts to prove that citrus clones are subject to senescence, and it is questionable whether the supposed rejuvenation is explainable as a permanent genetic factor change due to a nutritional effect or may be better explained by Frost's (*20*) theory of "islands" of mutating tissue in the nucellus.

Evaluation of Breeding Methods

Mass selection from open-pollinated seedlings was the method of citrus breeding followed by the early citrus growers. It has yielded important results over long periods, but it is not now followed by any of the United States workers in this field. The search for bud variations and the use of hybridization are so much more promising that the method will be revived only for use in special cases.

The practical bearing of a rapid mutation rate in citrus has already been discussed in detailing the improvement of varieties. The question of the cause of such variations remains to be considered. It has been pointed out that Frost had postulated islands of tetraploid nucellar tissue as a possible explanation of the variation in apogamic seedlings, and the little that is known as to the cytological basis of citrus bud mutations has been ably discussed by Frost (*20*). The worker in this field does not have a background of abundant experimental data and must make use largely of the principles established by workers with more facile plant material such as maize, *Nicotiana*, etc., in developing useful theories.

On this basis Frost summarized the situation. Bud variations presumably originating in single cells by gene mutation or by differential mitosis are frequent in citrus. Frost says:

> In the former case, at least, their somatic expression is doubtless favored by the presence of numerous heterozygous recessive genes. The production of recognizable bud variations, then, requires bud formation in an area of variant tissue, and may often be due to irregular tissue development in periclinal chimeras. The abundance of bud variation with some citrus forms apparently depends upon a permanent chimeral condition of the types in question.

The selection of bud mutations as a tool in citrus breeding has yielded some important results. Apogamic seedlings following interspecific crossing have given rise to the Davis grapefruit, the Silverhill satsuma orange, and the Oklawaha sour orange. In this group may be included the Everglade and Palmetto limes and Weshart and Trimble tangerines, although the supposed difference in these strains from the parental varieties has not warranted their continuance as distinct varieties. Evidence as to the behavior of the Lue orange indicates that this variety is apparently a nucellar seedling of the Valencia variety. A group of unnamed navel orange seedlings derived from seed of the Washington Navel pollinated with trifoliate orange pollen but showing no hybrid characters offer promise in securing new navel varieties adapted to Gulf coast conditions. In the same series, crosses made on the Thomson Navel gave only worthless fruits of the dry type, while a large percentage of the apogamic seedlings of the Washington Navel are vigorous growers and produce juicy fruits of more or less merit. If some of these prove to fruit satisfactorily under Florida and Gulf coast conditions, a navel variety may be found to meet the need in this section.

The work of Shamel and his coworkers in bud selection has preserved the original strains of commercial varieties and also yielded some superior new ones, as already detailed.

Chace, Church, and Denny (*8*, *9*) studied the inheritance of fruit composition in 18 mutant strains of Washington Navel orange and several mutant strains of Eureka and Lisbon lemons isolated by Shamel, Scott, Pomeroy, and Dyer (*63*, *64*). Chace and coworkers concluded that differences in the chemical composition of fruit exist between mutant strains, and that these are heritable. In Washington Navel strains some of these differences were closely connected with physical differences and others not. The differences generally found were in quantities of peel, oil, insoluble solids, and acids. Less variation was found in the specific gravity of the fruits and in the soluble solids and sugars of the juice. Strains of fruit with smooth skin were found to contain only small quantities of oil. In the Lisbon lemon mutants significant differences were found in specific gravity of fruit, proportion of rind, and percentage of acids; and in the Eureka lemon, in percentage of acids.

Haskins and Moore (*27*) observed premature flowering, albinism, fasciation, twisting, and peloric leaf formation in citrus seedlings grown from X-rayed seeds.

Selection within self-fertilized lines as a tool has little or no value in citrus breeding on account of polyembryony in most citrus types. The experience of Frost (*20*) at the Citrus Experiment Station has

shown that there is great loss of vigor and fertility with selfing. Toxopeus (*74*) and others have shown that the pummelo has no nucellar embryony and is usually self-pollinated. The progeny are usually quite uniform, and in such cases it is possible to develop more highly homozygous races by selection within self-fertilized lines.

Hybridization as a means toward the improvement of citrus varieties was undertaken by the Department in 1892 and has been continued ever since, and the progenies produced are being extensively tested in cooperation with the California, Florida, Texas, and Alabama experiment stations and many citrus growers (*70*, *71*, *84*, *86*). Some concrete results of definite value have been achieved as a result of this cooperation, as detailed under the improvement of citrus varieties above. Frost, in California, has carried on valuable work in this field since 1914, which has recently yielded promising citrus varieties. The work in Florida carried on by Camp and Jefferies, in Alabama by Yates, and in Texas by Yarnell and Wood was begun quite recently, and not enough time has elapsed to yield any definite results.

United States Department of Agriculture Breeding Results

Breeding work by the Department was initiated by Webber and Swingle and is carried out on the cooperative testing basis with the agricultural experiment stations and citrus growers in the subtropical fruit regions. The major part of the work is concerned with interspecific hybrids in which (1) the mandarin orange type is crossed with other citrus types with the object of securing high color of rind and flesh and also the "bouquet" of the tangerine in hybrid forms; (2) the lemon and lime are crossed with each other and with other citrus types; (3) bigeneric crosses of the trifoliate orange are made with species in other genera, primarily to increase the hardiness of the offspring; and (4) various crosses are made to explore the possibilities in other directions. The practical results from this work have been previously considered in the text and are summarized in table 7 of the appendix.

Mandarin Crossed With Other Citrus

Among the interspecific crosses that have given the most interesting results is the cross of the mandarin orange species on the grapefruit. In no case were hybrids produced when grapefruit pollen was transferred to the mandarin orange stigma, but the reverse operation has yielded abundant results.

The first crosses of this nature were made by Swingle in 1897 and by Webber in 1898. Webber and Swingle found wide variation in the F_1 progeny. Out of the first crosses two varieties were introduced, as already indicated, but in these the susceptibility to scab of the grapefruit parent was apparently dominant, and in addition the fruits were of such character that the keeping and shipping quality was unsatisfactory.

During the period 1908–12 Swingle, E. M. Savage, and F. W. Savage made a second series of crosses of a similar nature. The results were similar to those already stated, except that a number of the progeny were highly resistant to citrus scab and also possessed good shipping quality. An attempt was made to proceed a step farther through

selection from segregating seedlings in the F_2 generation, but on account of excessive nucellar embryony only one seminal seedling of merit was secured, which gave rise to a tangelo variety of promise, the San Jacinto. This was introduced in 1931.

A further attempt was made to secure desirable types by backcrossing the tangelo on the grapefruit, and in this case a fair number of seminal offspring were secured. In growth habit these resembled the pollen parent, the Sampson tangelo, but they were less vigorous. The fruit of two such backcrosses proved to be small, round, pink-fleshed, of low acidity and high sugar content, characters not present in either parent. One variety of the pink-fleshed backcross has been introduced as the Wekiwa.

Crosses made between the satsuma orange and the sweet orange have given rise to types somewhat similar to those secured by the tangerine-grapefruit cross with the flesh color and shape of the satsuma and the tight rind and size of the sweet orange (Ruby), but with high acidity and late maturity not found in either parent.

The third series of grapefruit-tangerine crosses were made by Traub, Robinson, and Savage, 1934–36, with the object of producing "seedless" tangelos. Marsh and its mutation, Thompson, and Davis, all "seedless" varieties, were used in place of Bowen, a seedy variety, which was chiefly utilized in previous crosses. These so-called "seedless" varieties are highly self-sterile and intersterile and produce few or no seeds even in mixed plantings.

Crosses between the tangerine and the sweet orange generally gave types similar to the latter but of small size.

Lemon-Lime Crosses

Among crosses between the lime and the lemon, the Perrine lemon, a promising variety, was found to be immune to citrus scab and lime withertip. It has already been mentioned and will be discussed more fully under disease resistance later.

Trifoliate Orange Crossed With Citrus and Fortunella Species

Citrus hybrids involving trifoliate orange (*Poncirus trifoliata*) as one parent have given rise to interesting results. The crosses were made by Swingle and Webber beginning in 1893 and at several times subsequently. In the first series 212 crosses were made and 13 hybrids (citranges, i. e., trifoliate × sweet orange) were secured. Most of these had the trifoliate orange as the seed parent, but in one case (Rusk citrange) the sweet orange produced the seed. There was wide variation in the characters of the hybrids. In most cases the leaves were of the trifoliate type, but unifoliate types were also secured. All were evergreen in habit; in fruit character there was also great variation in size, color, etc. In all cases the rind oil character was inherited from the trifoliate parent, and in most cases the juice character was intermediate. In none of the fruits was the juice character sufficiently like that of the sweet orange to give these fruits any prospect of commercial usefulness. Most of the progeny produced only nucellar embryos when an attempt was made to secure an F_2 generation by self-pollination, except in the case of the Sanford and Phelps citranges, which showed hybrids with segregation for leaf

characters. Seedlings of these segregating varieties were distributed for trial but thus far have produced nothing of special merit.

Hybrids were later secured by crossing the citrange and the kumquat. As a result the objectionable oil content of the fruit was reduced and an acid fruit type secured which has been called the citrangequat. One of the progeny, the Thomasville, shows high resistance to citrus canker, which was inherited apparently from the kumquat ancestor. The citrange crossed with calamondin has given an acid fruit type in which the disagreeable oil is eliminated. It has been called the Glen citrangedin. This type is relatively frost-resistant. Attempts made to secure the F_2 generation have been unsuccessful, since only nucellar embryos were secured.

Other Citrus Crosses

The lime crossed with the kumquat has given rise to small acid-fruited progeny which are immune to lime withertip and decidedly more frost-resistant than the true limes.

Various other crosses were made involving pummelo, sour orange, and other citrus species. The most interesting is the cross between the Eustis limequat, with a haploid chromosome number of 9, and the Hong Kong kumquat (*Fortunella hindsii*), with a haploid chromosome number of 18. This has given rise to a triploid hybrid, as reported by Longley, resembling the Hong Kong kumquat but larger and of greater vigor. It is of potential value in further crossing to secure seedless kumquat types, since many triploids are self-sterile and intersterile.

Inheritance in Citrus and Related Species

A number of hypotheses have been advanced to explain the wide variation in the progeny secured in the F_1 generation citrus crosses. Webber (*84*) in 1905 suggested that there must be some influence, either direct or indirect, of male parent on nucellar embryos, that the male element imparts the tendency to the segregation of characters that exist in the mother parent—characters that as a rule are probably of very mixed origin—but does not transmit any characters of the male parent. The Mendelian principles of unit factors, dominance, and segregation seemed inadequate to Swingle to account for his observations, and in 1913 he proposed the hypothesis of zygotaxis (*67*).

Swingle defined his hypothesis of zygotaxis as—

> the arrangement in syngamete (zygote) of the chromatin and other hereditary substances derived from the parental gametes and the persistence of this arrangement in the cells produced by the subdivision of the syngamete.

In further explanation of his hypothesis he states:

> It is assumed that the particular zygotactic arrangement taken up by the chromosomes of the parental gametes usually persists with little or no change throughout the life of the organism * * *. The fundamental idea underlying the term zygotaxis is that the architecture of the zygote with reference to its idioplastic particles, as well as its mechanisms for transmitting hereditary tendencies into expression, is determined to some extent at the moment of fusion of the two parental gametes and that this arrangement of parts is transmitted to the cells of the organism to which the zygote gives rise.

The hypothesis of zygotaxis was vigorously opposed by Hagedoorn and Hagedoorn (*25*) and by White (*89*). The former workers suggested that variable F_1 progeny in citrus crosses apparently are due

to habitual self-sterility and the sexual production of seeds. White points out that the F_1 variation in citrus hybrids, in the light of the data at hand, apparently results from differences in the gametic composition of the heterozygous parents.

Frost (*20*) sums up the evidence for and against the theory of zygotaxis and states that—

> enough is known of the production of new characters by new combinations of genes in crossing to warn us against setting any narrow limits to the probable results of recombinations in crosses between two highly heterozygous species. * * * It is concluded, from the available evidence, that citrus forms are in general extremely heterozygous. * * * This conception seems highly significant. * * * In the evolution of heterozygosis, polyembryony probably was an important factor.

Frost suggested that lethal and sublethal effects in selfing and crossing may be the result of homozygosis of inevitably unfavorable genes and may also be in part a result of incompatible recombinations. Heterosis, however, according to Frost, is probably more often secured in crossing.

Inheritance of Disease Resistance

The various citrus types and varieties show great variation in inheritance of resistance or susceptibility to various diseases. The summary given in table 3 is based largely on the text by Fawcett (*15*).

Winston, Bowman, and Bach (*90*) studied the resistance of citrus types and varieties to sour orange scab, *Sphaceloma fawcetti*, and found the following not susceptible: Kumquat; citron; Kansu orange (*Citrus junos* Tan.); Mexican, Woglum, and Tahiti limes; Royal and Triumph grapefruit; Cuban shaddock; Bergamot orange; most sweet oranges; and Cleopatra mandarin. The work of Peltier and Frederich (*52*) has shown that citrus scab cannot survive under California conditions, indicating that susceptibility under certain conditions may not be apparent.

Fulton (*22*) made a study of the susceptibility of citrus types and varieties to Key lime withertip or anthracnose (*Gloeosporium limetticolum*). He found that the West Indian (Key) lime and the Dominican (thornless) lime are highly susceptible. Other lime varieties have not given undoubted evidence of susceptibility. Hybrid West Indian limes, sweet orange, grapefruit, lemon, *Citrus nobilis*, and others have proved immune. Since only two types are highly susceptible, it is suggested that other closely related varieties might be substituted in culture. It is interesting to note that susceptibility seems not to be a dominant factor in F_1 hybrids.

Peltier and Frederich (*51*) made extensive studies of the susceptibility of *Citrus* and related genera to citrus canker (*Pseudomonas citri*) under greenhouse and Gulf coast conditions. Lee (*41, 42*) made similar studies in the Orient. Although there is no immediate need for varieties and stocks resistant to citrus canker, since the epidemic in the upper Gulf coast and in Florida has been practically eradicated since 1925, it is of advantage to select resistant types where possible as an insurance in case the disease should be inadvertently reintroduced. Grouped in order of susceptibility, varieties of grapefruit and pummelo (shaddock) proved extremely susceptible (except two pummelo varieties, Hirado and Siam, and the Triumph grape-

Table 3.—*Relative susceptibility of citrus species and varieties and related species to principal diseases*

[++ indicates high, + medium, and ± slight susceptibility, − indicates high degree of immunity or practically complete immunity]

Species or variety	Mal di gomma (foot rot)	Brown rot gummosis [1]	Psorosis	Bark rot of Orient	Decorticosis	Melanose	Sour orange scab	Sweet orange scab	Australian citrus scab	Canker	Blast	Citrus anthracnose [2]	Key lime anthracnose	Black spot (*Phoma*)	Phyllosticta leaf drop of Orient	Leprosis (nail-head rust)	Mal secco
Sweet orange (*Citrus sinensis*)	++	++	++	−	−	++	−	++	±	+	++	+	−	++		++	−
Sour orange (*C. aurantium*)	−	−	±		−	++	++	−	++	+	+	+				−	++
Lemon (*C. limonia*)	++	++			++	+	++		++	+	+	+		+		±	++
Rough lemon	+	+	−			+	++									±	
Lime (*C. aurantifolia*):																	
Key lime		+				+	−			++		−	++			+	+
Sweet lime		+					±	+		+			−				+
Citron (*C. medica*)	++	+			−	+	−			±		+				±	++
Grapefruit (*C. grandis*)	+	+	+	−	−	++	++		−	++	+	+		+	+	−	+
Pummelo (*C. grandis*)	+	++	+	−	−	++	+			++	+	+		+		−	+
King orange (*C. nobilis*)							+			+				+			
Tangerine (*C. nobilis* var. *deliciosa*)	+	+	++	++	−	+	+	+	+	±	±	+		+		±	−
Satsuma (*C. nobilis* var. *unshiu*)	+	±		++	−	+	+		+	±	±	+		+	++	−	−
Calamondin (*C. mitis*)		−		±			++			±							
Kumquat (*Fortunella* spp.)		−					±			±							
Trifoliate orange (*Poncirus trifoliata*)							+			++							+
Eremocitrus glauca (Lindl.) Swingle							−			−							
Severinia buxifolia (Poir.) Ten.		−					−			−							
Chaetospermum glutinosa (Blanco) Swingle										++							
Citropsis spp.										−							

[1] Some pummelo varieties resist brown rot gummosis; others are very susceptible.
[2] Anthracnose of citrus other than Key lime.

fruit). Lemon varieties and the trifoliate orange (*Poncirus trifoliata*) are only slightly less susceptible than grapefruit. Classed as moderately susceptible are the sweet oranges, sour oranges, citrons, and limes, except that the Tahiti lime is much less susceptible than the Mexican lime. The mandarin group (*Citrus nobilis* varieties) as a whole is only slightly attacked, as is also the calamondin. The outstanding resistant members of the edible citrus fruit group proved to be the kumquats (*Fortunella* spp.), except the susceptible Hong Kong kumquat (*F. hindsii*), resistance in kumquats amounting to practical immunity under field conditions.

The extensive citrus canker tests made by Peltier and Frederich (*51*) afforded opportunities for testing the numerous hybrids developed by the Department, these hybrids involving reciprocal crosses between numerous species and varieties ranging in their reaction to canker infection from extremely susceptible to very resistant. The results of these tests may be briefly summarized as follows. All the trifoliate orange first crosses proved quite susceptible to canker, like the parent, *Poncirus trifoliata*. In the second cross, that is, citranges crossed with other parents, those hybrids with the mandarin orange or the kumquat as one parent proved decidedly resistant; in fact, the citrangequat (Thomasville variety) proved practically immune, fully as much so as the kumquat. Likewise the limequat and the orangequat can be regarded as similar to the satsuma in resistance. The calamondin, while somewhat resistant itself, does not carry this resistance into the hybrid, with one exception, the citrangedin (citrange × calamondin). Most of the grapefruit hybrids have proved quite susceptible, although certain of the tangerine and satsuma crosses with grapefruit (tangelos) show enough canker resistance to place them beside the mandarin oranges in their resistance to canker. Peltier and Frederich conclude: "In the search for promising canker-resistant plants the results of over 4 years' investigations seem to point to the fact that our best plants will come from the hybrids."

Gummosis, a disease caused by *Phytophthora citrophthora*, has been studied by Klotz and Fawcett (*37*), who tested 78 species and varieties for resistance. The sour oranges proved very resistant, while the lemons were most susceptible. Klotz (*36*) has shown that the resistance apparently is due to some cellular product of the host that has an inhibiting action on the fungoid enzymes.

Toxopeus (*75*) reported that the factor or factors for resistance to foot rot (*Phytophthora parasitica*) might possibly be recessive, and in that case he suggests that selection for individuals resistant to this disease be made in the second generation (F_2) after crossing

Inheritance of Capacity to Produce Vitamins

Preliminary tests have been made indicating how capacity to produce vitamins is transmitted in citrus hybrids. The only published report (*71*) has to do with tests made in 1928 with the Sampson and Thornton tangelos, comparing the vitamin B content of these hybrids with that of the parental varieties, grapefuit and tangerine. These tests, made by the Bureau of Chemistry and Soils of the Department, were summarized as follows:

Both charts are in agreement in showing tangerine juice to be a better source of vitamin B than the juice of the other fruits fed, and also that tangelo juice is approximately equal in vitamin B potency to grapefruit juice. Therefore, with respect to vitamin B production the tangelo has inherited the characteristics of the grapefruit (*71, footnote, p. 3*).

With respect to vitamin C, which is of still more importance in the citrus fruits, tests are in progress and some indications as to inheritance have already been secured. These preliminary tests (*13*) were made during the 1935–36 season by Esther P. Daniel, Bureau of Home Economics, in cooperation with Traub and Robinson, Bureau of Plant Industry, of the Department. In these tests the ascorbic acid content of fruit samples at maturity was determined by the titration method. The figures below indicate milligrams of ascorbic acid per cubuc centimeter of juice:

The Thornton and Orlando tangelos (range 0.33 to 0.35) gave results approxi, mating those of the Bowen grapefruit parent (average 0.35); the Sampson-Minneola, and Seminole (range 0.18 to 0.28) proved more like the Dancy tangerine parent (average 0.24). One variety that was grouped with the tangelos, the Umatilla, but that in fact is a hybrid between satsuma and Ruby oranges, gave a much higher content of ascorbic acid (0.40) than the true tangelos. The Clement tangelo, which has the Clementine as the pollen parent, had the highest content (0.64). The Clementine is reputed to be a natural hybrid between the sour orange and the tangerine and has a higher content of ascorbic acid (0.37) than the Dancy (0.24).

The Perrine lemon—a hybrid of lemon and lime—appears to inherit from the lemon parent rather than from the lime, having an ascorbic acid content of 0.40 as compared with 0.22 in the lime.

The limequat (Lakeland) ranks low (0.17), like the lime parent. It is interesting to note that the sweet lime (often called sweet lemon) has a fairly high ascorbic acid content (0.33), despite its almost complete lack of citric acid. Apparently there is no positive correlation between citric and ascorbic acid content.

Results at State Stations

California

The hybridization work at the Citrus Experiment Station at Riverside was begun by Frost (*17*) in 1914, and since that date pollinations were made mainly in 1915, 1916, 1928, 1929, and 1931. More work of this nature is planned for the next 2 or 3 years. The work consists of selfing and crossing and the study of genetic variation in nucellar seedlings.

In general the work is confined to crosses between species and within the mandarin orange group, *Citrus nobilis*. In all cases selfing of the parents is carried along as far as practicable with the work of crossing. In all, six varieties of sweet orange, three of grapefruit, and four of lemon have been used in crossing. Within the mandarin group four varieties were used in crosses. The chief results so far have been secured by selection within the first generation (F_1), but promising F_1 hybrids have been selfed, and crosses have been made between promising hybrids and standard varieties.

The F_1 hybrid combinations represented by at least one individual include the following: Lemon and mandarin (tangemon), mandarin and mandarin (of distinct botanical varieties), orange and mandarin (tangor), grapefruit and mandarin (tangelo), grapefruit and orange (orangelo), lemon and orange (oramon), and grapefruit and lemon (lemelo). The most promising hybrids not yet introduced seem to

be the following: One each from King mandarin × Dancy tangerine (fruit of very good size, fair shape, and very good flavor); from Mediterranean Sweet orange × Dancy tangerine (very good fruit color and flavor, extra early); and from satsuma (Owari) × Lisbon lemon (fruit rough, very juicy, seedless, high in acid, excellent in aroma).

The most promising results have been secured by crossing within the mandarin group. Three varieties already mentioned have been introduced, and at least two or three more are under consideration as candidates for introduction. The earliest work at the Citrus Experiment Station led to the use of the King mandarin as the main seed parent in these crosses.

During the last few years certain hybrids from crosses of lemons with grapefruit and of "hedge bergamot" with grapefruit have been studied as possible stock types for lemons. On the basis of tree characters, seed production, and resistance to inoculated phytophthora gummosis, several hybrids have been selected for further trial, and a preliminary study of seedlings has been made. At present one hybrid from Imperial grapefruit × hedge bergamot and one from Eureka lemon × Imperial grapefruit seem most promising, although it is not certain whether they have enough nucellar embryony to produce adequately uniform seedlings for rootstocks.

A general survey including 3,800 trees is under way in a search for genetic differences from the seed parent. Tetraploids are listed and studied, and a special study is being made of a few other progenies showing unquestionably variant characters (dry fruit from one parent tree, nonnavel fruit and pollen production from two navel parent trees without pollen, late-ripening fruit from one parent tree). A study of possible genetic differences in fruit shape (satsuma) and pulp color (blood orange) among progeny of the same seed-parent tree has also been undertaken.

The related specialized studies carried on by Frost include:

(1) *Polyembryony.*—Counts of total embryos and counts of generative and nucellar seedlings have been made for horticultural varieties, tetraploid and diploid nucellar progeny, and F_1 hybrids. Among about 1,200 hybrids, 10 cases of duplicate hybrids (two identical hybrids from one seed) have been found, obviously the result of embryonic fission. Nucellar embryos seem to be somewhat less abundant with tetraploids than with corresponding diploids.

(2) *Triploidy and tetraploidy.*—About 2 percent of about 3,800 nucellar seedlings were tetraploid and have been especially studied. These are of no horticultural value. A few hybrids have recently been produced by crossing a tetraploid with diploids as pollen parents; the reverse combination failed to produce seed. About 1½ percent of about 1,200 hybrids have been proved to be triploid, none tetraploid; several times as many are suggestive of triploidy, but their chromosome constitution has not been determined.

(3) *Chromosome behavior.*—Preliminary studies have been made on chromosome conjugation and segregation in diploids, triploids, and tetraploids, and on irregularities at the microsporad stage.

(4) *Clonal senescence.*—Studies are in progress on various juvenile characters of young seedlings and clones, especially thorniness, scarcity of flowers, and general vigor of growth, and on their decline with increasing age from seed and increasing length of shoot growth.

(5) *Chimeras and bud variation.*—Studies of tree and fruit characters have been made on forms that seem to be chimeral, in the general variety collection of citrus.

Florida

The citrus hybridization work by Camp and Jefferies at the Florida State Citrus Experiment Station, Lake Alfred, with acid citrus fruits was begun in 1924. Numerous crosses have been made, including 18 different combinations, with the following as parents: Calamondin; Rangpur lime; Meyer, Genoa, and Villa Franca lemons; Jamaica and Key limes; and the limequat. The F_1 progency have reached the fruiting stage and are under test.

The work carried on in cooperation with the Department is concerned with bud selection and with the testing of the citrus varieties originated by the Department.

The citrus progeny testing collection, begun in 1921, contains 52 strains of oranges, tangelos, grapefruit, and tangerines selected from record trees, and these have been intensively studied. From the superior strains budwood has been distributed in quantity to nurserymen. Selections from Thompson and Marsh grapefruit and Valencia, Hamlin, Parson Brown, Temple, and Pineapple oranges are in greatest demand.

The Department hybrids have been tested out over a long period. According to the latest report, the utilization of Rusk and Morton citranges as rootstocks for the satsuma orange is promising.

Alabama

The citrus work of the Alabama Agricultural Experiment Station, begun in 1933 in cooperation with the Department, is concerned with the testing out of over 50 strains of the satsuma orange, both early- and late-maturing, and with the selection in the F_2 generation of citrange, particularly for high quality fruit and cold resistance. The experiments have not been carried on for a sufficient period to yield concrete results, although several of the recently introduced satsuma orange strains appear promising for hardiness, early bearing, and fruit quality.

Texas

The citrus breeding work begun by Yarnell and Wood at the Texas Agricultural Experiment Station in 1934 comprises a study of the adaptability of citrus varieties and citrus relatives, both for fruit and rootstock purposes; mass selection of open-pollinated citrange seedlings, primarily for cold resistance; crossing and selfing in sweet orange, mandarin orange, grapefruit, and acid citrus fruits. In all cases of crossing and selfing some cytological studies of root tips, buds, and young fruits are also carried along.

The following rootstock plants introduced primarily by the Department are under test: (1) *Balsamocitrus paniculata* Swingle; (2) citradia; (3) *Citrus aurantifolia*—Key, Mexican, Rangpur, Tahiti; (4) *C. aurantium*—African, Bittersweet, Brazilian, Paraguay, Roubidoux, Rough Seville, standard Sour; (5) *C. bergamia* Risso; (6) *C. ichangensis;* (7) *C. grandis*—Triumph; (8) *C. limetta* Risso—sweet lime; (9) *C. limonia*—Keller, Meyer, Perrine, Ponderosa, Rickart, Rough; (10) *C. maxima* Marr.—Chinese pummelo, Cuban and Pink shaddocks; (11) *C. medica*—Diamante, Etrog, Indian, Italian; (12) *C. mitis*—calamondin; (13) *C. nobilis*—Cleopatra; (14) *C. sinensis*—Oroville,

Weldon, Raymondville; (15) citrange; (16) citrangedin—Glen; (17) citrangequat—Thomasville; (18) citrumelo (citrange × pummelo); (19) limequat—Lakeland, Tavares; (20) Suen Kat orange; (21) tangelo—Altoona, Clement, Lake, Minneola, Sampson, Seminole, Thornton, Umatilla, Wekiwa, Yalaha.

The following crosses have been made: (1) Sweet orange—Ruby × Hamlin, Valencia × Hamlin, Ruby × Meyer lemon and reciprocal, Parson Brown × Meyer lemon and reciprocal, Parson Brown × Ponderosa lemon, Pineapple × Pink Marsh grapefruit, Valencia × citron; (2) mandarin orange and hybrids—Meyer lemon × Clementine tangerine, Meyer lemon × Owari satsuma, Owari × Hamlin orange, Owari × Pink Marsh grapefruit, Thornton × Clementine, Thornton × Pink Marsh; (3) grapefruit—Meyer lemon × Pink Marsh, Pineapple orange × Pink Marsh, satsuma orange × Pink Marsh, Thornton tangelo × Pink Marsh; (4) acid citrus fruits—Meyer lemon × Pink Marsh grapefruit, Meyer lemon × Mexican lime, Meyer lemon × Clementine tangerine, Meyer lemon × Eureka lemon, Meyer lemon × citron, Meyer lemon × Ruby orange, Meyer lemon × satsuma orange, Meyer lemon selfed, Parson Brown orange × Meyer lemon, Parson Brown orange × Ponderosa lemon.

The citrus varieties originated by the Department, and also introductions from abroad, have been tested out on a cooperative basis since 1930. The most promising variety in the testing collection at the Texas substation at Weslaco up to the present time is the Texas Navel, to which reference has already been made. In cooperation with the Department more than 50 strains of the satsuma orange, both early and late maturing, are under test at Texas substations at Angleton and Winter Haven, and attempts to select desirable individuals of high quality and resistant to low temperatures in second generation citrange progeny are under way at College Station.

Hawaii

The Hawaii Agricultural Experiment Station (*28*) reports that rootstock and variety tests are in progress to determine the suitability of various combinations of scion and rootstock to different sites and soils. Many recent introductions of promise are being tested in comparison with the older standard varieties.

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APPENDIX

UNITED STATES SUBTROPICAL AND TROPICAL FRUIT-BREEDING STATIONS AND EARLY AND PRESENT WORKERS

[An asterisk (*) designates workers all or part of whose salaries were or are paid from Federal funds]

(1) United States Department of Agriculture, Washington, D. C.:
Early workers—*H. J. Webber, *W. T. Swingle, *Eugene May, *Frank W. Savage, *R. E. Caryl, *L. B. Scott.
Present workers—*Hamilton P. Traub, senior horticulturist; *T. Ralph Robinson, senior physiologist; *Edward M. Savage, assistant plant breeder; *A. D. Shamel, principal physiologist; *C. S. Pomeroy, associate pomologist; *A. E. Longley, associate botanist.

(2) Alabama Agricultural Experiment Station of the Alabama Polytechnic Institute, Gulf Coast Substation, Fairhope:
Present workers—*Harold F. Yates, acting superintendent.

(3) Arizona College of Agriculture and the Agricultural Experiment Station, Tucson:
Present workers—W. E. Bryan, head of Department of Plant Breeding (date breeding).

(4) California College of Agriculture and the Agricultural Experiment Station of the University of California:
Early workers—C. S. Milliken, C. L. Dyer, F. N. Harmon.
Present workers—H. J. Webber, emeritus professor of subtropical horticulture, Riverside; Ira J. Condit, associate professor of subtropical horticulture, Riverside; L. D. Batchelor, director of Citrus Experiment Station, Riverside; Robert W. Hodgson, head of Division of Subtropical Horticulture, Los Angeles; R. E. Caryl, associate in orchard management, Riverside; H. B. Frost, associate plant breeder, Riverside.

(5) College of Agriculture and Agricultural Experiment Station of the University of Florida:
Early workers—H. H. Hume, John Belling.
Present workers—H. S. Wolfe, horticulturist in charge, Subtropical Experiment Station, Homestead; A. F. Camp, horticulturist in charge, Citrus Experiment Station, Lake Alfred; J. H. Jefferies, superintendent, Citrus Experiment Station, Lake Alfred.

(6) Glen St. Mary Nurseries Co., Glen St. Mary, Fla.:
Early workers—G. L. Taber (trifoliate rootstock investigations), H. Harold Hume (persimmon investigations).

(7) University of Hawaii and the Hawaii Agricultural Experiment Station:
Early workers—*J. E. Higgins, *V. S. Holt, *J. M. Westgate.
Present workers—*J. H. Beaumont, principal horticulturist; *W. T. Pope, senior horticulturist; *R. H. Moltzan, principal scientific aide; *J. C. Thompson, principal scientific aide; *W. B. Storey, junior biological aide.

(8) Louisiana State University and Agricultural and Mechanical College and the Agricultural Experiment Station:
Present worker—J. C. Miller, horticulturist in charge of research.
(9) Puerto Rico Agricultural Experiment Station, Rio Piedras, Puerto Rico:
Early worker—O. W. Barrett.
Present worker—Julio S. Simons, agronomist for plant introduction and propagation.
(10) Federal Experiment Station, Mayaguez, Puerto Rico:
Early workers—*O. W. Barrett, *Holger Johansen, *T. B. McClelland.
Present worker—*C. L. Horne, associate horticulturist.
(11) Panama Canal Zone Experiment Gardens, Summit:
Present workers—*J. E. Higgins, consultant in plant introduction and utilization; *Walter R. Lindsay, acting director.
(12) Commonwealth of the Philippines, Department of Agriculture and Commerce (citrus, avocado, pineapple, and papaya breeding):
(a) Bureau of Plant Industry, Manila:
Early workers—C. F. Baker, T. P. Reyes, P. J. Wester.
Present workers—J. P. Torres, J. de Leon, F. Galang, F. K. Morada.
(b) College of Agriculture, University of the Philippines, Department of of Agronomy, Laguna:
Present workers—N. B. Mendiola, plant breeder and geneticist; J. M. Capinpin, plant breeder and cytologist; T. Mercado, assistant plant breeder.
(13) Texas Agricultural Experiment Station:
Present workers—S. H. Yarnell, chief, Division of Horticulture, College Station; J. F. Wood, horticulturist, Weslaco; H. M. Reed, horticulturist, Angleton.

Subtropical and Tropical Fruit-Breeding Stations in Foreign Countries and Workers and Present Work

Europe and North Africa

Spain:
(1) Estacion Naranjera de Levante, Burjasot, Valencia (citrus breeding):
Present worker—Manuel Herrero.
Italy:
(2) Regia Stazione Sperimentale de Olivicoltura ed Oleificio, Pescara (olive breeding):
Present worker—Julio Savastano.
(3) Regia Stazione Sperimentale di Frutticoltura e de Agrumicoltura, Arcieale, Catania, Sicily (breeding for resistance to mal secco in lemons).
French Morocco:
(4) Experimentation Fruitière et Maraichère, Rabat (citrus breeding):
Present workers—F. Lacarello, Director; Ch. Miedzyrzecki, geneticist.
Greece:
(5) Hellenic Kingdom Superior School of Agriculture, Laboratory of Horticulture, Athens (olive and fig variety studies):
Present worker—P. Th. Anagnostopolous.

Asia and Malaya

Palestine:
(6) Jewish Agency, Agricultural Experiment Station, Rehoboth (citrus breeding):
Early worker—J. D. Oppenheim.
Present worker—Ch. Oppenheimer.
(7) Agricultural School, Mikweh-Israel (collection of Jaffa orange bud mutations):
Present worker—S. Yedidja.
India:
(8) Poona, Bombay Presidency; Horticultural Section (1) Ganeshkhind Fruit Experiment Station, Kirkee; (2) Modibag (Garden), College of Agriculture, Poona. (Improvement of citrus, mango, papaya, pineapple, guava, pomegranate, fig, banana, jujube, annona.)
Early workers—W. Burns, S. H. Prayag, L. B. Kulkarni, H. P. Paranjpe.
Present workers—G. S. Cheema, horticulturist and professor of horticulture; P. G. Dani, assistant; S. R. Gandhi, assistant; S. S. Bhat, assistant; B. Nazareth, assistant.

(9) Department of Agriculture, Bihar (mango and papaya breeding):
Present workers—R. Zarbakht-Kahn, horticulturist; R. Shah, assistant; S. Prashad, assistant.

(10) Royal Agricultural and Horticultural Society of India, Alipur, Calcutta (variety studies of tropical fruits):
Present worker—Sydney Percy Lancaster.

(11) Government Gardens, Saharanpur, United Provinces (lime, mango, and loquat improvement):
R. D. Fordham, deputy director.

Straits Settlements and Federated Malay States:

(12) Department of Agriculture, Kuala Lampur (pineapple breeding):
Present worker—W. D. P. Olds, director of agriculture.

Siam:

(13) Department of Agriculture and Fisheries, Bangkok (variety studies of tropical fruits):
Present worker—Luang Suwan, director general.

China:

(14) College of Agriculture, Lingnan University, Canton; Department of Horticulture (variety studies of citrus, avocado, mango, papaya, pineapple, banana, lychee, diospyros, annona, artocarpus, Chinese olive (*Canaria*), etc.):
Present workers—G. Weidman Groff, professor of horticulture; Pui-man Lei, Iu-nin Shiu, A. N Benemerito.

Japan:

(15) Imperial Horticultural Experiment Station, Okitsu (fig, loquat, and citrus breeding):
Present worker—T. Tanikawa, acting director.

(16) Chiba Horticultural College, near Tokyo (loquat variety studies):
Present worker—Taiji Miki, professor of pomology.

(17) Shizuoka Agricultural Experiment Station (bud mutations of satsuma orange):
Present worker—Kimijiro Noro, pomologist.

(18) Taihoku Imperial University, Formosa (citrus breeding):
Present worker—Tyozaburo Tanaka, professor of citriculture.

(19) Agricultural Experiment Station, Shirin, Taihoku, Taiwau (subtropical fruit crops breeding):
Present worker—Y. Sakurai, pomologist.

Netherland East Indies:

(20) Buitenzorg Botanical Gardens (improvement of citrus and other tropical fruits):
Present workers—G. J. A. Lirra, horticultural adviser; H. J. Toxopeus, geneticist.

South and Central Africa

Union of South Africa:

(21) Division of Plant Industry, Union of South Africa; Subtropical Horticultural Research Station, Nelspruit, Eastern Transvaal (papaya and pineapple breeding):
Present worker—J. D. J. Hofmeyr, research horticulturist.

(22) Department of Pomology, University of Stellenbosch (fig and olive variety trials):
Present worker—O. S. H. Reinecke, head of department of pomology.

Southern Rhodesia:

(23) Citrus Experimental Station, Mazoe (citrus variety trials):
Present worker—L. A. Lee, horticulturist.

Zanzibar, East Africa:

(24) Department of Agriculture (variety trials—citrus, banana, pineapple, mango, papaya, lychee, and rambutan):
Present worker—A. J. Findley, director.

Nigeria:

(25) Agricultural Department, Ibadan (breeding of pineapple, and variety trials with citrus, mango, avocado, and papaya):
Present worker—E. H. G. Smith, agricultural botanist.

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Australia and New Zealand

Victoria:

(26) Department of Agriculture, Division of Horticulture, Melbourne (bud selection in citrus):

Present worker—J. M. Ward, superintendent of horticulture.

New South Wales:

(27) Grafton Experiment Farm and the Hawkesbury Agricultural College (citrus breeding).

Queensland:

(28) Department of Agriculture and Stock, Brisbane (improvement of citrus, avocado, mango, papaya, pineapple, date, olive, granadilla, persimmon, fig, loquat, and guava):

Present worker—(Appointment of research staff in fruit crops now under consideration).

(29) Queensland Acclimatisation Society, Brisbane (introduction of tropical and subtropical fruits):

Present worker—R. Allsopp, overseer.

New Zealand:

(30) Department of Agriculture, Horticulture Division, Wellington (citrus, avocado, and olive variety trials):

Present worker—J. A. Campbell, director, Horticulture Division.

(31) Department of Scientific and Industrial Research, Plant Research Bureau, Mount Albert, Auckland (subtropical fruit variety trials):

Present worker—Dr. Allen.

Mexico, Central America, and the Antilles

Mexico:

(32) Estacion Experimental:

(a) Acapulco, Guerrero (mango, lime, pineapple, and avocado).
(b) Oaxaca, Oaxaca (mango, lime, avocado).
(c) Jalapa, Veracruz (papaya, mango, pineapple).
(d) Colima, Colima (lime).
(e) Leon, Guanajuato (avocado).
(f) Queretaro, Queretaro (avocado).
(g) Coalan del Rio, Morelos (papaya).
(h) Hecelchakan, Campeche (avocado).

Honduras:

(33) Lancetilla Experiment Station (United Fruit Co.), Tela (Extensive tropical fruit variety trials):

Present worker—Wilson Popenoe, agricultural director.

British Honduras:

(34) The Agricultural Office, Belize (introduction and testing of citrus varieties):

Present worker—H. P. Smart, agricultural officer.

Costa Rica:

(35) Alan Kelso, Aparto. 246, Punta Arenas. (Private work; tropical fruit crop introduction and improvement.)

Cuba:

(36) Agricultural Experiment Station, Santiago de las Vegas (variety tests and selections of citrus, avocado, mango, banana, and pineapple):

Early workers—M. Fortun, J. Ajete.

(37) Atkins Institution of the Arnold Arboretum (Harvard University), Cienfuegos (breeding of citrus and other tropical fruits):

Present worker—H. C. Gray, director.

Jamaica:

(38) Department of Agriculture, Hope, Kingston (papaya and banana breeding):

Present worker—L. N. H. Larter, Government botanist.

Trinidad, British West Indies:

(39) The Imperial College of Tropical Agriculture (banana and other tropical fruits breeding):

Present worker—E. E. Cheeseman, professor of botany.

South America

Chile:

(40) Salvador Izquierdo, Monedo 778, Santiago.

(Private work confined mostly to introduction of new varieties of subtropical fruits.)

Brazil:

(41) Instituto Agronomico do Estada de São Paulo, Genetics Department (citrus and banana breeding):

Present worker—C. A. Krug, head of department.

Argentina:

(42) Estacion Experimental de Concordia, Ministerio de Agricultura de la Nacion Argentina (citrus breeding):

Present worker—Ruben Bence Pieres, ing. agr. and director of the station.

TABLE 4.—*Chromosome numbers of Citrus species and varieties and related species (family Rutaceae) as far as determined up to 1936*

[See literature citations *18, 19, 23, 24, 33, 44, 45, 47, 49, 72*]

Species or variety	Chromosome number (n)	Authority and year determined	Remarks
Aeglopsis chevalieri	9	Longley, 1925	
Triphasia trifolia	9	do	
Triphasia trifolia var. *bivalens*	18	Longley, 1937	Determined in 1928.
Severinia buxifolia	9	Longley, 1925	Do.
Microcitrus australis	9	Longley, 1937	
Citropsis schweinfurthii	9	Longley, 1925	
Poncirus trifoliata	9	do	
Fortunella crassifolia	9	do	
F. margarita	9	do	
F. japonica	9	do	
F. hindsii	18	do	
Citrus medica	9	do	
C. limonia	9	Frost, 1925 Longley, 1925	
C. limonia var. *bivalens*	18	Frost, 1925	
C. aurantifolia	9	Longley, 1925	
C. grandis	9	do Frost, 1925	
C. aurantium			Undetermined.
C. sinensis	9	Frost, 1925; Longley, 1925; Oppenheimer and Fraenkel, 1929.	
C. sinensis var. *bivalens*	18	Frost, 1925	
C. nobilis	9	Longley, 1925	
C. nobilis var. *deliciosa*	9		Quoted by Oppenheimer (*49*) without citation of author.
C. nobilis var. *unshiu*	9	Nakamura, 1929	
C. mitis	9	Longley, 1925	
C. ichangensis			Undetermined.

TABLE 5.—*Citrus species and varieties introduced by the United States Department of Agriculture*

Species	Common or varietal name	Native habitat	Source of introduction	Where now available	Remarks
Citrus grandis	Shaddock	Southeastern Asia	Original habitat; also Australia, West Indies, South Africa.	Orlando, Eustis, Coconut Grove, and Lake Alfred, Fla., Riverside, Calif., Weslaco, Tex.	Cuban shaddock is being tested for possible use as rootstock; Arajan (pink,) Alamoen
Do	Pummelo	Southeastern Asia, Malaysia.	Siam, China, India, Philippines, Hawaii.	Eustis, Fla	The following varieties are being tested for utilization of fruit and resistance to saline soil solution: Kao Pan, Kao Phuang, Thong Dee, Nakorn, Victoria, Siam, Pandan Wangi, Better Pummelo, Wong Yau, Banda, Indian Red.
Do	Grapefruit	do	South Africa	do	Cecily grapefruit, reputed to be a seedless mutation, being tested for difference, if any, from standard seedless varieties.
C. aurantium	Sour, Bigarade, or Seville orange.	China, southeastern Asia.	Original habitat; also Spain, North Africa, West Indies, Australia.	Orlando, Eustis, Coconut Grove, and Lake Alfred, Fla., Riverside, Calif.	For testing as semihardy and disease-resistant stocks for use in hybridization, for utilization as marmalade fruits.
	Chinotti		Southern France	do	A preserving fruit; also useful as a potted dwarf plant.
	Bergametto (bergamot orange).		Sicily	do	Used in preparing flavoring extracts and perfumes.
C. sinensis (sweet orange).	Washington Navel or Bahia Navel.	China, southeastern Asia.	Brazil	do	The original introduction which served as a basis for developing the orange industry of California. Other varieties, as the Thomson Navel, have sprung from this variety. Not adapted to Florida culture.
	Texas Navel	do	do	Weslaco, Tex., Riverside, Calif.	Several navel types (seedless) introduced by Dorsett, Shamel, and Popenoe; one of which is being propagated in southern Texas as the Texas Navel for testing and breeding.
	Algerian	do	Algeria	Orlando and Eustis, Fla	Reputed to be productive and of good quality; being tested, not yet fruiting.
	Matidja	do	do	do	Do.
	Zatina	do	do	do	Do.
	Chamoudi (Shamooti)	do	Palestine	Orlando, Eustis, and Coconut Grove, Fla., Riverside, Calif., Weslaco, Tex.	A large seedless orange, famous as the "Jaffa" orange in European markets; for testing its adaptability and for use in hybridization.
	Capuchin	do	Chile	Orlando, Eustis, and Oneco, Fla.	Small, hardy orange; useful as potted ornamental and in breeding.
	Telde	do	Canary Islands	Orlando and Eustis, Fla	Small-fruited sweet orange; reputed of high quality; for testing and breeding.
	Lau Chang, Hang Chang.	do	China	do	Sweet orange reputed to be of high quality; for testing and breeding; not yet fruiting.
	Harvard	do	Cuba	Orlando, Coconut Grove, and Eustis, Fla.	An early-maturing orange, reputed to be of hybrid origin; for testing.

	Tankan	do	Formosa	do	A small, disease-resistant, late-maturing orange of high color. Used for testing and breeding.
	Rico	do	Puerto Rico	Orlando and Eustis, Fla., Riverside, Calif., Weslaco, Tex.	Rico, nos. 1 to 6. Six selections made from seedling oranges, for seedlessness and quality; not yet fruiting.
	Selecta	do	Brazil	do	Parent variety of the Washington Navel.
	Byfield seedless	do	Australia	Orlando, Fla	Reputed to be a midseason orange, seedless, of good quality. Not yet fruiting.
C. nobilis var. *deliciosa* (mandarin group)	Ponkan	China	China and Taiwan	Orlando, Eustis, Coconut Grove, and Oneco, Fla., Riverside, Calif.	A large, free-peeling orange, early to midseason, disease-resistant, highly esteemed in the Orient; for testing and breeding.
	Clementine		Algeria	do	Reputed to be a natural hybrid of tangerine and sour orange, but resembles tangerine; use in crosses with grapefruit gave rise to Clement tangelo.
	Suen Kat (sour mandarin).	China	China	do	Serves as budding stock for best mandarin varieties of China and Formosa; being tested as stock; for hardiness and disease resistance.
	Changsha	do	do	Orlando, Fla., Fairhope, Ala	Very hardy, free-peeling orange; promising for use in breeding.
	Chin Kom	do	do	Orlando, Fla	Not yet fruiting.
	Sun Chu Sha	do	do	do	Do.
	Hung Kat	do	do	do	Do.
	Beauty (Ellendale) tangerine		Australia	do	To be tested for fruit quality, size, disease resistance, and hardiness.
	Vermilion tangerine	China	China	do	Do.
C. nobilis var. *unshiu* (satsuma orange).	Kawano (early); also about 40 similar early-maturing satsuma mutations.	Japan	Japan	Fairhope and Silverhill, Ala., Eustis, Fla. (in part), Winter Haven, Tex. (in part).	These large-fruited, early-maturing satsuma varieties make possible earlier shipment of the commercial crop—avoiding frost risk and competition with tangerines. Being tested for stock affinity, hardiness, stability of type, fruit quality; also used in cross pollinations.
	Ikiriki, Suzuki, Hiri, Kashima, Mizomoto, Miyasaki.	do	do	do	Satsuma varieties of local fame in Japan, being tested for possible superiority to standard variety (Owari) in United States; for hardiness, fruit quality, size of fruit, etc.
C. medica (citron)	Corsican, Spatafora, Peretto, Java, Diamante, Chinese, Etrog.	India	Italy, Sicily, Corsica. Greece.	Orlando, Eustis, Coconut Grove, and Oneco, Fla., Weslaco, Tex., Riverside, Calif.	Varieties of citron adapted to the preserving industry are being tested for productiveness, disease resistance, and quality; hybrids being made to improve existing forms. Commercial citron growing has made a start in Florida, Puerto Rico, and California, but information is needed on stocks, varieties, disease resistance, etc. There is a limited demand for the Etrog variety, used in certain Jewish ceremonials; its form must accord with a fixed standard.

TABLE 5.—*Citrus species and varieties introduced by the United States Department of Agriculture*—Continued

Species	Common or varietal name	Native habitat	Source of introduction	Where now available	Remarks
C. limonia (lemon)	India, Simla, Mazoe (wild types).	India, southeastern Asia.	India, South Africa	Orlando, Coconut Grove, and Eustis, Fla.	Testing importations in comparison with the "Florida rough lemon" for stock use and disease resistance.
	Algiers (seedless)	do	Algeria	Coconut Grove, Fla	Testing for adaptation to a humid climate, stock adaptability, and disease resistance.
	Meyer	China	China	Orlando and Eustis, Fla., Weslaco, Tex., Fairhope, Ala.	Testing for hardiness, stock adaptability, fruit quality, and disease resistance; also in hybridization work. This variety has been in commercial production for several years in Florida and the Gulf coast region; has proved quite hardy.
	Sumatra	Sumatra	Sumatra	Orlando, Fla., Weslaco, Tex	Not yet fruiting.
C. aurantifolia (lime)	Woglum	India, Malaysia, southeastern Asia.	India	Orlando and Coconut Grove, Fla.	Testing for seed content, fruit quality, productiveness, disease resistance; used in hybridizing.
	Giant, Cameron, Debe, Dominica.	do	West Indies	Orlando and Eustis, Fla	Tests of these introduced varieties indicate the names are local names for the common Mexican (or West Indian) lime, similar to the Florida Key lime.
	Sweet	do	Palestine	Orlando, Fla., Weslaco, Tex	Used to a limited extent as a stock; fruit insipid.
	Java	do	Java	do	Not yet fruiting.
C. mitis	Calamondin	Philippine Islands	China, Philippine Islands	Orlando, Eustis, and Coconut Grove, Fla., Weslaco, Tex., Fairhope, Ala.	A semihardy, limelike fruit, of possible use as a stock and serving as an excellent lime substitute. Crossed with the citrange it has given rise to an extra-hardy hybrid, the Glen citrangedin, an excellent "ade" fruit for the home fruit garden.
C. ichangensis		China	China	Orlando, Eustis, and Coconut Grove, Fla.	A very hardy form of citrus, of possible use as stock and for breeding purposes. "Ichang lemon", apparently a hybrid or large-fruited form.
C. junos Sieb	Yuzu	do	Japan	Orlando and Eustis, Fla	A hardy lemonlike form of citrus of possible use as a stock, as a lemon substitute in cool regions, and for breeding purposes.
C. hystrix		Philippine Islands, Malaysia.	Philippine Islands	Orlando, Coconut Grove, and Eustis, Fla., Summit, Canal Zone.	Fruits lemonlike but usually too aromatic to be edible; of possible use as stocks; not hardy.
	Kalpi	do	do	do	Fruits large, oblate, with edible lemonlike pulp; of vigorous growth; promising as a stock.

TABLE 6.—*Citrus relatives (Rutaceae) introduced by the United States Department of Agriculture*

Species	Common name	Native habitat	Source of introduction	Where now available	Remarks
Aegle marmelos (L.) Correa	Bael fruit	India	India	Orlando, Coconut Grove, Eustis, and Lake Alfred, Fla., Riverside, Calif., Mayaguez, P. R., Summit, Canal Zone.	Deciduous, semihardy, producing an edible fruit; chiefly used in sherbet.
Aeglopsis chevalieri Swingle		Tropical West Africa	West Africa	do	Fruit not edible, but for testing as stock.
Atalantia citroides Pierre		Cochinchine	Cochinchine	Orlando, Lake Alfred, and Coconut Grove, Fla., Summit, Canal Zone, Mayaguez, P. R.	Fruit not edible; for testing as stock; decidedly ornamental—columnar habit, dark green foliage.
A. disticha (Blanco) Merr., *A. missionis* (Wight) Oliv.		Cochinchine, Java	Java	Orlando, Fla	Very resistant to salt and alkali; serves well as a stock for citrus species, decidedly promising for alkali or salty soils.
Afraegle paniculata (Schum. and Thonn.) Engl., *Balsamocitrus dawei* Stapf., *Afraegle gabonensis* (Swingle) Engl.	"Powder pear"	West Africa, central Africa, French Equatorial Africa.	Original habitats	Orlando, Lake Alfred, and Coconut Grove, Fla., Summit, Canal Zone, Mayaguez, P. R.	Fruits not edible; of possible use as citrus stocks; ornamental; not hardy.
Swinglea glutinosa (Blanco) Merr.	Tabog	Philippine Islands	Philippine Islands	do	A large forest tree; serves well as a citrus stock in warm soils; resistant to disease and vigorous.
Chalcas koenigi (L.) Kurz		India	India	Orlando and Coconut Grove, Fla.	Foliage used extensively in the Orient for flavoring curries; readily propagated from root cuttings; useful as an ornamental; not hardy.
Clausena lansium (Lour.) Skeels.	Wampi	South China	South China	do	Fruit subacid, small, of good quality; of possible use as a stock; lemon buds readily on this stock but on other citrus species with difficulty.
Citropsis schweinfurthii (Engl.) Swing. and M. Kell.	Cherry orange	Central Africa	Central Africa	Orlando, Lake Alfred, Coconut Grove, and Eustis, Fla., Riverside, Calif., Summit, Canal Zone.	This species appears to be closely related to citrus, serves fairly well as a citrus stock in warm locations; resistant to common citrus diseases. The large compound leaves and numerous flowers make the tree decidedly ornamental.
C. gabonensis (Engl.) Swingle and M. Kell.		French Equatorial Africa.	Africa	do	Do.
Eremocitrus glauca (Lindl.) Swingle.	Desert kumquat	Australia	Australia	Orlando, and Eustis, Fla., Indio and Riverside, Calif., Sacaton, Ariz.	A xerophytic plant of possible use as a citrus stock in dry regions; a hybrid has been secured between this species and a citrange, which is of greatly increased vigor and may serve as a citrus stock.

TABLE 6.—*Citrus relatives (Rutaceae) introduced by the United States Department of Agriculture*—Continued

Species	Common name	Native habitat	Source of introduction	Where now available	Remarks
Feronia limonia (L.) Swingle	Wood apple	India, Ceylon, Indo-China.	India	Orlando and Lake Alfred, Fla., Riverside, Calif., Summit, Canal Zone, Mayaguez, P. R.	Fruit used in preserves; tree useful as an ornamental in warm locations; also being tested as a stock.
Feroniella oblata Swingle	Krassang	Cambodia	Cambodia	do	Fruit used as a condiment.
F. lucida (Scheff.) Swingle	Kavista Batu	Java	Java	do	Fruits edible; both species of *Feroniella* ornamental and of possible use as a stock.
Fortunella hindsii (Champ.) Swingle.	Hong Kong kumquat	China	China	Orlando and Lake Alfred, Fla.	Fruits used as a condiment, but are very small and bitter; chiefly of interest as the plant has proved to be a tetraploid; crosses are being made with this species to secure seedlessness; one such cross, a triploid, has been secured.
Glycosmis pentaphylla (Retz.) Correa.		India, Indo-China	India	Orlando, Lake Alfred, and Coconut Grove, Fla., Summit, Canal Zone, Mayaguez, P. R.	Fruits small. Chiefly of use as an ornamental; not hardy.
Hesperethusa crenulata (Roxb.) M. Roem.	Naibel	Ceylon	Ceylon	Orlando and Lake Alfred, Fla., Summit, Canal Zone, Mayaguez, P. R., Eustis, Fla.	Fruits sometimes used as a condiment. Chiefly used as an ornamental. Stock tests gave unions with citrus, but not vigorous.
Lavanga scandens (Roxb.) Buch. Ham.	Lavanga	India	India	Orlando and Lake Alfred, Fla., Summit, Canal Zone, Mayaguez, P. R.	Climbing shrubs.
Merrillia caloxylon (Ridley) Swingle.		do	do	Orlando and Coconut Grove, Fla.	Chiefly of value as an ornamental; not hardy.
Microcitrus australasica (F. Muell.) Swingle.	Finger lime	Australia	Australia	Orlando, Eustis, and Lake Alfred, Fla., Riverside, and Indio, Calif., Summit, Canal Zone, Mayaguez, P. R.	These Australian species are drought-resistant and are being tested as stocks. They are semihardy and useful as ornamentals. The fruits are scarcely edible, except possibly the last named, which has not yet fruited.
M. australis (Planch.) Swingle	Dooja				
M. garrowayi (Bailey) Swingle	Garroway's Finger lime.				
M. inodora (Bailey) Swingle	Russell River lime				
Paramignya monophylla Wight, *P. longipedunculata* Merr.		India	India	Orlando and Lake Alfred, Fla., Summit, Canal Zone, Mayaguez, P. R.	Climbing shrubs.
Poncirus trifoliata (L.) Raf.	Trifoliate orange	China	China	Orlando and Eustis, Fla., and Fairhope, Ala., Winter Haven, Tex.	This deciduous citrus relative is extremely hardy and useful as a stock in the northern limit of citrus culture, especially for the satsuma orange. Two forms have been noted, the normal small-flowered form and a large-flowered form of seemingly greater vigor. The trifoliate orange has been used in numerous hybrids, as the citranges and citrangequats.

Severinia buxifolia (Lam.) Ten.	"Box-leaved orange"	South China	South China	Orlando, and Eustis, Fla., Fairhope, Ala., Summit, Canal Zone, Mayaguez, P. R.	This shrubby tree is resistant to salt and may serve as a citrus stock. It is chiefly of use in ornamental hedge plantings. Several strains have been selected from imported seed of varying vigor and thorniness. Its immunity to citrus canker recommends it as a substitute in hedge plantings for the susceptible *Poncirus trifoliata*. Used as a dwarfing stock, it causes early flowering, hence is useful in hybridizing.
Triphasia trifolia (Burm. f.) P. Wils.	Lime berry	Unknown. (Widely distributed in tropical regions.)	Java	Orlando, Eustis, and Lake Alfred, Fla., Riverside, Calif., Summit, Canal Zone, Mayaguez, P. R.	A shrub or dwarf tree, chiefly of use as an ornamental; resistant to salt; fruits used sometimes in preserves.

TABLE 7.—*Summary of citrus breeding by the United States Department of Agriculture*

[Hybrids or selections introduced by the Department, 1892–1934]

Breeding procedure	Year introduced	Name of hybrid or variety	Parentage	Remarks
1. Hybridization through controlled cross-pollination:				
(a) Interspecific: F_1 hybrids	1904	Sampson and Thornton tangelos.	Dancy tangerine × Bowen grapefruit.	These early introductions proved susceptible to scab and were poor shippers, with a short season of maturity.
	1931	Orlando (Lake), Seminole, Minneola, Yalaha tangelos.	do	This series of tangelos introduced in 1931 gave varieties high in quality, maturing from October to May, scab-resistant, and of good shipping quality.
	1931	Clement tangelo	Clementine tangerine × Bowen grapefruit.	A soft-fleshed hybrid for the home fruit garden; not recommended for commercial planting.
	1931	Umatilla tangelo	Satsuma orange × Ruby orange.	Classed with the tangelo group which it resembles; very late maturing; scab-resistant.
	1931	Perrine lemon	Genoa lemon × Mexican lime.	Fruit of size, shape, and quality of commercial lemon; highly resistant to scab and withertip; vigorous and productive.
F_2 hybrids	1931	San Jacinto tangelo	Seedling segregate of an unnamed tangelo of little promise.	Adapted to conditions in the hot interior valleys of the Southwest, where most tangelos have been disappointing.
Backcrossing hybrids on parent variety.	1931	Wekiwa tangelo	Sampson tangelo × grapefruit.	Tree resembles pollen parent (Sampson) though less vigorous; fruit small, sweet, pink-fleshed, unlike either parent.
(b) Intergeneric: Bigeneric hybrids, F_1 generation.	1904	Sanford, Rusk, Willitts, and Phelps citranges.	Trifoliate orange (*Poncirus trifoliata*) × sweet orange (*Citrus sinensis*).	The citranges with one exception (Rusk) had the trifoliate orange as the female parent. They failed in producing a hardy edible orange, owing to an excess of acrid oil in rind and pulp, but are proving useful as stocks and for further work in hybridization.
	1905	Morton citrange		
	1906	Colman, Rustic, and Savage citranges.		
	1911	Saunders and Cunningham citranges.		
	1923	Eustis and Lakeland limequats.	Mexican lime (*Citrus aurantifolia*) × round kumquat (*Fortunella japonica*).	The limequats have proved similar to the lime in fruit quality, but much hardier and resistant to lime withertip.
	1923	Tavares limequat	Lime × oval kumquat (*F. margarita*).	
	1932	Nippon kumquat, "orangequat".	Satsuma orange (*Citrus nobilis* var. *unshiu*) × Meiwa kumquat (*Fortunella crassifolia*).	This hybrid may be utilized in preserving like the kumquats, but is a much larger fruit borne on a more vigorous hardy tree. It also furnishes an excellent ade, owing to its acid, deep orange pulp.
Trigeneric hybrids, F_1 generation.	1933	Thomasville and Telfair citrangequats.	Willitts citrange × oval kumquat (*Fortunella margarita*).	In these crosses the objectionable oil of the citrange is reduced so that the fruits may serve as hardy lime substitutes in making ade. The Thomasville also proved immune to citrus canker, a character derived from the kumquat parent.
	1933	Sinton citrangequat	Rusk citrange × oval kumquat.	

TABLE 7.—*Summary of citrus breeding by the United States Department of Agriculture*—Continued

[Hybrids or selections introduced by the Department, 1892–1934]

Breeding procedure	Year introduced	Name of hybrid or variety	Parentage	Remarks
Trigeneric hybrids, F_1 generationr	1931	Glen citrangedin	Willitts citrange × calamondin (*Citrus mitis*).	In this cross the objectionable oil content of the citrange is eliminated, giving rise to an ade fruit similar to the calamondin but much more hardy.
2. Selection:				
(a) Seedlings (apogamic or nonhybrid).	1904	Weshart and Trimble tangerines.	Derived from Dancy cross-pollinated seed, but not hybrids.	Seedlings exhibiting apparently extra vigor and producing fruits of larger size than the parent variety.
	1905	Everglade lime	Grown from lime seed from cross-pollinated fruits, but not hybrids.	Apparently extra vigorous strains of the Mexican lime with some indications of withertip resistance.
	1906	Palmetto lime		
	1912	Davis (Little River) grapefruit.	Original seedling from cross-pollinated fruit of a seedy grapefruit (with Dancytangerine pollen); not a hybrid.	This seedling produced a new type of seedless grapefruit (4-6 seeds) with the fruit quality of the seedy grapefruit; indications are that it is a superior canning variety.
	1931	Silverhill satsuma orange.	Original seedling from cross-pollinated Owari satsuma (sweet orange pollen), but not a hybrid.	This variety exhibits extra vigor and hardiness, with large-sized fruit of good quality.
	1932	Oklawaha sour orange	Derived from cross-pollinated sour orange (sour pummelo pollen used), but not a hybrid.	Tree of vigorous productive character with large thick rind fruits adapted to use in marmalade preparation. This character has been transmitted in budded progeny.
Bud selection [1]	1921–36	Valencia, Lue (Lue Gim Gong), Pineapple, Parson Brown, and Homosassa oranges; King mandarin; Dancy and Oneco tangerines; Marsh, Duncan, Hall, Davis, Foster, and Thompson grapefruit.	Budwood secured from performance record trees; several progeny rows of each variety budded and grown under uniform conditions with record of yield, and special attention to the production of any off-type fruit. (1 progeny of Lue was discarded and replaced, owing to tendency to produce ridged fruits. A bud sport of the Parson Brown has been studied over a period of years and seems to be a chimeral mutation).	Under the terms of the cooperative agreement the disposition of budwood from the progeny grove is in the hands of the Florida Agricultural Experiment Station, and considerable demand has developed in recent years among growers and nurserymen for this true-to-type budwood of standard varieties. The experiment station, also under the cooperative agreement, is testing the new citrus hybrids introduced by the Department and maintains a collection of the citrus relatives furnished by the Department.

[1] Standard orange varieties as listed by the standardization committee of the Florida Citrus Seminar 1916; other citrus varieties selected and propagated in cooperation with the Florida Agricultural Experiment Station at the Citrus Experimental Station, Lake Alfred, Fla. For bud selection work in California, see table 8.

Table 8.—*Bud mutations in citrus discovered by Shamel and coworkers, of the United States Department of Agriculture, in cooperation with the California Citrus Experiment Station, Riverside, Calif., 1909–36*

SWEET ORANGE (WASHINGTON NAVEL STRAINS)

Strains	Characteristics	Date discovered	Remarks
Superior strains:			
Improved Washington.	Uniformly heavy production of uniformly desirable oranges.	1909	1,402,950 selected buds sold by Fruit Growers Supply Co. and estimated 2,000,000 otherwise distributed.
Robertson	Early maturity, resistant to "June drop."	1925	Plant patent 126.
Inferior strains:			
Thomson	Fruits generally lacking juice and flavor.	1909	Propagated sparingly in few districts.
Unproductive	Very low production	1913	Trees top-worked to Improved Washington.
Australian	Low production, poor fruit, rank growth.	1909	Do.
Willow-Leaf	Narrow leaves, small fruit	1915	Do.
Dry	Very little or no juice	1914	Do.
Yellow	Pale yellowish color of peel	1909	Do.
Brown-Spotted	Sunken brown spots on peel	1915	Do.
Golden Buckeye	Lacking in juice	1909	Do.
Golden Nugget	Lacking in juice; pale color of peel	1909	Do.
Dual	Uneven texture of rind	1914	Do.
Corrugated	Deeply and uniformly ridged fruit	1909	Do.
Ribbed	Shallow and uniformly ridged peel	1909	Do.
Seamed	Very shallow, narrowly seamed peel	1914	Do.
Fluted	Broadly and evenly ridged peel	1910	Do.
Flattened	Flattened shape of fruit	1909	Do.
Pear-Shape	Pyriform shape of fruit	1909	Do.
Elliptical	Oval shape of fruit	1909	Do.
Sheepnose	Small, pear-shaped fruit, enclosed navels.	1915	Do.
Rolled-Leaf	Rolled leaves, unproductive	1921	Do.
Minor importance	Many strains of minor economic importance but originating from bud mutations.	1909–36	Do.

SWEET ORANGE (VALENCIA STRAINS)

Strains	Characteristics	Date discovered	Remarks
Superior strain:			
Improved Valencia	Uniformly heavy production, uniformly good quality of fruit.	1912	2,337,000 selected buds sold by Fruit Growers Supply Co., and estimated 2,250,000 buds otherwise distributed.
Inferior strains:			
Unproductive	Very low yields	1912	Trees top-worked to Improved Valencia.
Willow-Leaf	Narrow leaves, small fruits	1912	Do.
Dwarf	Small tree, low yields	1912	Do.
Persistent-Style	Style tends to remain with fruit	1915	Do.
Flattened	Flattened shape of fruit	1912	Do.
Long	Long or oblong shape of fruit	1912	Do.
Fluted	Broadly, evenly, and smoothly ribbed fruit.	1912	Do.
Corrugated	Deeply ridged, rough texture of rinds	1912	Do.
Ridged	Sharply and unevenly ridged rinds	1912	Do.
Coarse	Coarse, rough texture of rinds	1912	Do.
Yellow	Pale color of peel	1912	Do.
Misshapen-Leaf	Irregularly shaped leaves, low yields	1914	Do.
Small Smooth	Very small fruit, smooth, very thin rinds.	1912	Do.
Variegated	Leaves light and dark green	1915	Do.
Minor strains	Many economically unimportant strains differing in tree and fruit characteristics from all others.	1912–36	Do.

LEMON (EUREKA STRAINS)

Strains	Characteristics	Date discovered	Remarks
Superior strain:			
Improved Eureka	Heavy yields of uniformly good lemons.	1911	767,000 selected buds sold by Fruit Growers Supply Co., and estimated 1,250,000 buds otherwise distributed.

TABLE 8.—*Bud mutations in citrus discovered by Shamel and coworkers, of the United States Department of Agriculture, in cooperation with the California Citrus Experiment Station, Riverside, Calif., 1909–36*—Continued

LEMON (EUREKA STRAINS)—Continued

Strains	Characteristics	Date discovered	Remarks
Inferior strains:			
Small-open	Small-sized fruits	1911	Trees top-worked to Improved Eureka.
Pear-shape	Pyriform-shaped fruits	1911	Do.
Shade-tree	Vigorous tree growth; coarse, thick rinds.	1911	Do.
Unproductive	Very low yields	1911	Do.
Corrugated	Strongly ridged and coarse-textured rinds.	1911	Do.
Ribbed	Evenly ribbed texture of rinds	1911	Do.
Variegated	Leaves light and dark green, fruits ridged.	1912	Do.
Striped	Light stripes on fruits	1912	Do.
Crumpled leaf	Crumpled appearing leaves, low yields.	1911	Do.
Minor strains	Many strains originating from bud mutations of minor economic importance.	1911–36	Do.

LEMON (LISBON STRAINS)

Strains	Characteristics	Date discovered	Remarks
Superior strains:			
Improved Lisbon	Heavy production of uniformly desirable fruits.	1913	86,215 selected buds sold by Fruit Growers Supply Co., and estimated 125,000 buds otherwise distributed.
Dense-productive	Vigorous growth, resistant to wind damage.	1913	Do.
Inferior strains:			
Open	Spreading tree growth, susceptible to sunburn.	1913	Trees top-worked to Improved Lisbon.
Unproductive	Very low yields	1913	Do.
Ribbed	Ridged texture of rind	1913	Do.
Corrugated	Heavily ridged and very coarse-textured rinds.	1913	Do.
Collared	Bottle-shaped with necked stem ends.	1913	Do.
Striped	Light-colored stripes on rinds	1913	Do.
Thornless	No thorns	1920	Do.
Minor strains	Many strains of minor commercial importance but of scientific interest.	1913–36	Do.

GRAPEFRUIT (MARSH STRAINS)

Strains	Characteristics	Date discovered	Remarks
Superior strains:			
Improved marsh	Heavy production of uniformly desirable fruits.	1910	1,262,757 buds sold by Fruit Growers Supply Co. and estimated 750,000 buds otherwise distributed.
Dawn	Early maturity of fruits	1927	
Inferior strains:			
Corrugated	Ridged texture of rinds	1910	Trees topworked to Improved Marsh.
Seedy	Excessive number of seeds	1910	Do.
Pear shape	Pyriform-shaped fruits	1910	Do.
Minor strains	Several strains of minor commercial importance but of scientific interest.	1910–37	Do.

TANGERINE (DANCY STRAIN)

Strains	Characteristics	Date discovered	Remarks
Superior strain:			
Improved Dancy	More regularly productive	1915	56,973 selected buds sold by Fruit Growers Supply Co.

TABLE 8.—*Bud mutations in citrus discovered by Shamel and coworkers, of the United States Department of Agriculture, in cooperation with the California Citrus Experiment Station, Riverside, Calif., 1909–36*—Continued

LIME STRAINS

Strains	Characteristics	Date discovered	Remarks
Superior strains:			
Improved Mexican	Selected for size of fruits	1924	5,163 selected buds sold by Fruit Growers Supply Co.
Improved Bearss	Selected for heavier production	1928	

NOTE.—*The article entitled Improvement of Subtropical Fruits other than Citrus, by Hamilton P. Traub and T. Ralph Robinson, appears in the 1937 Yearbook Separate on Improvement of Subtropical Fruits.*

[Omitted from 1937 Yearbook]

IMPROVEMENT OF SUBTROPICAL FRUITS OTHER THAN CITRUS

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FIG IMPROVEMENT

THE domesticated fig, a member of the genus *Ficus* in the mulberry family (Moraceae), is one of the most ancient of cultivated fruits. The available evidence, according to Werth (*134*),[1] indicates that the fig was first domesticated in the mountainous region of northwestern India, Afghanistan, and Baluchistan. It then spread south, west, and east to Asia Minor and the Mediterranean region and via Turkestan to central and southern China. The genus *Ficus* contains more than 600 species, but only a few are cultivated for their fruits, and of these *F. carica* L., the common cultivated fig, is the most important. It is a truly subtropical species, thriving best in the region between the true Tropics and the Temperate Zone, but *F. roxburghii* Wall., a tropical evergreen species native to India, thrives on the southern edge of the subtropical region and into the Tropics. It may prove valuable in hybridizing.

According to a recent survey made by Heintz (*34*), the fig is grown primarily in the Mediterranean countries—Turkey in the region of Smyrna, Italy, Spain, Algeria, Portugal, Greece, France, Tunis, and Morocco. Other regions of production are in the United States, Chile, and Australia. An attempt is now being made to build up the industry in the Union of Soviet Socialist Republics, in the Crimea, Caucasus, and Turkistan, where figs have been grown for centuries, but where the industry is not now in a thriving condition.

The fig was introduced into the United States along with other subtropical fruits by the early Spanish settlers, in Florida and the upper Gulf coast region, and was brought into California by the Mission Fathers, probably as early as 1710, and into Arizona at an early date. It was grown for home consumption in southern California, Arizona, southern Texas, and the region along the upper Gulf coast to northern Florida, Georgia, and South Carolina for many years before commercial development took place in the regions to which it is well adapted in California and Texas. Approximately 90 percent of the commercial fig crop is produced in California and the remainder in Texas. Figs are important for local consumption in the Southeastern States.

The minute flowers of the fig tree are borne on the inside of a hollow pear-shaped receptacle with an opening or eye at the apex more or

[1] Italic numbers in parentheses refer to Literature Cited, p. 70.

less closed by scales. This aggregate whole is called the "fig" even before maturity. The individual flowers may be pistillate (containing ovules) or staminate (pollen bearing). Short-styled nonfunctional pistillate flowers that contain the egg or larva of a fig wasp are known as gallflowers. According to Condit (*21*), there are four horticultural types of the domesticated fig:

(1) The caprifig type, from which the other types have apparently originated, produces both gallflowers and flowers with mature stamens and therefore pollen. The gallflowers serve as breeding chambers for the very small fig wasp (*Blastophaga psenes* L.), which serves as a pollinating agent for the next type.

(2) The Smyrna type produces only pistillate flowers, and its fruits mature only after pollination from caprifigs. It has been grown for many centuries in a small valley in Asia Minor and is named for the seaport where the figs are packed and shipped. Through the centuries a dependent relationship has developed between the Smyrna and caprifig types, the former being dependent for pollination on the latter, through the agency of the fig wasp. When the female wasp issues from the mature caprifig it carries pollen on its body, and, seeking a place for egg laying, it enters the eye opening of the receptacle of the Smyrna type varieties, thus effecting pollination. Egg laying in these edible varieties is prevented by the length of the style, and the insect usually departs, but it has served its purpose in transferring pollen. In horticultural practice the caprifigs, containing the mature *Blastophaga*, are suspended in the spring of the year in the Smyrna type fig trees, and the *Blastophaga* in great numbers then issue from the caprifigs and carry the pollen into the receptive Smyrna type figs. One or two caprifig trees will usually furnish a sufficient supply of the *Blastophaga* for 100 of the Smyrna type trees. The process is called caprification.

BREEDING *work with most of the subtropical fruits is only at its beginning in this country, but in the case of several of these fruits we are fortunate in having extensive collections of germ plasm brought in from tropical countries by such enthusiastic plant explorers as David Fairchild, Wilson Popenoe, P. H. Dorsett, W. T. Swingle, and the late Frank N. Meyer. These germ-plasm collections are being materially augmented by W. E. Whitehouse and his coworkers in the Department of Agriculture. Many valuable selections of superior strains and varieties have been made from this rich store of material, but its chief value today lies in the fact that it is available for hybridizing as fast as desirable objectives are determined and breeding techniques are worked out. With the fig, the avocado, the pineapple, the mango, the granadilla, and the papaya, hybridizing work is now in progress.*

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(3) The White San Pedro type combines the characteristics of both the Adriatic and the Smyrna types in one tree. The brebas or first-crop figs are parthenocarpic, while the second-crop figs on new wood of the same branch are nonparthenocarpic, hence requiring caprification to set fruit. The outstanding varieties are the White San Pedro and the Gentile.

(4) The common or Adriatic type does not require pollination to set fruit. Varieties such as the Adriatic, Kadota (Dattato, White Endich), Magnolia (*126*), Celeste, Mission, and Brown Turkey belong to this group.

Earlier Work in the Improvement of Figs

The fig plantings today are based almost entirely on varieties secured by mass selection over long periods of time, and their exact origin is unknown. The history of fig improvement in the United States up to the present is concerned chiefly with the selection, from a great many introduced varieties, of those that are more or less adapted to particular regions for utilization as fresh, dried, or canned fruit. The early attempts at fig breeding in the southeastern United States by Jope in Texas (1875) and Massey in North Carolina and South Carolina (1903) were doomed to failure, since they utilized seeds secured from imported Smyrna figs, which produced types requiring pollination (*19*). B. W. Hunt, of Eatonton, Ga., made crosses by cutting an opening into the fruit and transferring the pollen to the pistillate flowers on the end of a knife blade. He used Celeste, Green Ischia, and Brown Turkey as pistillate parents (*46, 47*). One of his originations, the Hunt variety, is still available and may be of value in breeding experiments. Crosses made in California by Rixford (fig. 1), of the United States Department of Agriculture, have given rise to a few promising varieties of caprifigs, including Kearney, Forbes, and Excelsior. Francis Heiny, of Brawley, Calif., has used three species in his hybridization work—*Ficus carica*, *F. pseudo-carica* Miq., and *F. palmata* Forsk. Some first-generation hybrid edible types are promising, as well as hybrid caprifigs that produce pollen in all three crops (*17, 19*). In most caprifig varieties stamens are scarce or lacking except in the profichi or main spring crop.

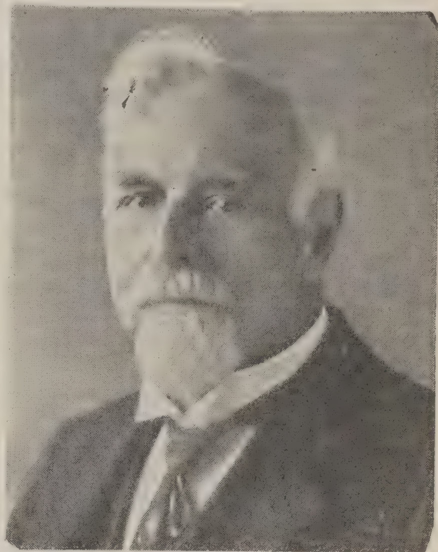

Figure 1.—Gulian P. Rixford (1838–1930), who introduced the Smyrna fig from Asia Minor in 1880. As crop physiologist of the United States Department of Agriculture, 1908–29, he developed and introduced improved varieties of caprifigs and of the Smyrna type and contributed to the improvement of the avocado as well as the cherimoya, pomegranate, pistache, persimmon, and other subtropical fruit crops in California.

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The planting of seedlings of the Smyrna type fig by Maslin (*62*) in the 1880's in California threw light on the nature of the Smyrna fig-production problem, as will be indicated in the next section, and in addition gave some practical breeding results. When his 139 seedlings came into fruit in 1901, 53 percent were caprifigs and the balance of the edible or Smyrna type (*19*). Selections from these were named and distributed by G. P. Rixford and W. T. Swingle, of the Department of Agriculture, under a cooperative arrangement between the owner and the Department, and include the following Smyrna type figs: Rixford, Eisen (a self-sealing fig), Hilgard (reported as almost immune from splitting), and West (sweetest and best fig in the Maslin orchard). The caprifigs selected were Loomis, Newcastle, Mason, Bleasdale, and others. These have been widely distributed and some are highly regarded by growers (*94*, *116*, *117*).

Fig-breeding work by the Arizona Agricultural Experiment Station workers, at the Yuma Experiment Farm, covering an 8-year period prior to 1920, did not yield any superior varieties, and the project was abandoned.

The obvious faults of most cultivated varieties of the fig, as will be pointed out below, cause considerable economic loss and present a challenge to the plant breeder.

Many fig varieties were introduced into California during the nineteenth century, but only a few hold a permanent place today in the fig industry in the State.

It was unfortunate that during the last two decades, following the work of the pioneers during the latter half of the nineteenth and the first decade of the twentieth century, extensive plantings were made in California by development companies. However, this was not without some good results, for extensive trials of this nature showed clearly in which sections fig culture could be carried on most successfully. As a net result of the work of the pioneers and the later extensive commercial plantings, the fig industry is now being concentrated in the most productive sections and is based on four varieties—White Adriatic, Mission, Lob Ingir (Smyrna type, commonly called Calimyrna), and Kadota (Dattato), as pointed out by Condit.[2]

Various fig varieties of the Adriatic type were commonly grown in southern California for many years prior to the 1880's, when the White Adriatic variety, apparently introduced from Italy, took its place as the chief drying fig in the State. On the market it came into competition with the superior dried Smyrna product from Asia Minor. The Mission fig, which was introduced by the early mission fathers, was widely cultivated and is used as a secondary drying variety. Although it is in many respects an outstanding variety, it has a serious defect in its black color.

The Smyrna type of fig, the most suitable variety for drying (*15*), was introduced into California at an early date, but it failed to mature fruit on account of the absence of the *Blastophaga*, the natural agent in caprification—a relationship that was not fully understood at the time. Howard (*42*) details the attempts that were made to overcome the difficulty. In 1880–82 Gulian P. Rixford, of the San Francisco Bulletin, distributed some 14,000 cuttings of selected varieties of the

[2] CONDIT, I. J. THE STATUS OF THE CALIFORNIA FIG INDUSTRY. (Manuscript) 1935.

Smyrna fig imported from Asia Minor. When these trees reached bearing age the fruit invariably dropped before maturity. Various explanations were offered to account for this failure to mature fruit, except the true one—lack of pollination.

In further attempts to understand the difficulty, E. W. Maslin in 1887 planted seeds secured from the best imported Smyrna figs, and F. C. Roeding in 1888 planted at Fresno about 20 acres with Smyrna type figs from cuttings collected in Asia Minor by his nursery foreman, N. C. West. Cuttings of the wild fig or caprifig were in this importation. Mature pollen-bearing fig types thus became available in California, and the stage was set for a practical solution of the problem. The scientific researches of Solms-Laubach (*108*), Müller (*71*), and Mayer (*66*) had already indicated the necessity for pollination of the Smyrna type of fig and the function of the fig wasp in transferring the pollen.

The important ground work on pollination led George C. Roeding, son of F. C. Roeding, to attempt artificial pollination of immature Smyrna figs with pollen secured from caprifigs in 1890. He introduced the pollen into the Smyrna figs by means of a quill, and secured four mature fruits with viable seeds later in the season. The next season he used a glass tube drawn to a very small diameter at one end to introduce the pollen into the eye of the Smyrna fig, and discharged it by blowing into the larger end of the tube. About 150 fruits were secured by this means. Seeds from these fruits gave sufficient plants for 20 additional acres of figs by 1892.

In California Eisen (*26, pp. 151–152*) was apparently the first to understand fully the importance of the fig wasp in fig culture. He verified the work of George C. Roeding at Niles, Calif., and in 1885 published at Fresno a pamphlet, The Fig and Its Culture and Growing with Special Reference to California. This was followed by a second paper presented before the California Academy of Science in 1896. The Department of Agriculture then delegated Howard (*42*) to introduce the fig wasp into California. Several attempts had been made by individuals but had not proved successful. W. T. Swingle, who was at the time in the Mediterranean region, was delegated to send caprifigs containing gall insects to the Department at Washington for shipment to California. The first shipment from Italy arrived in 1898, too late to find host caprifigs in suitable condition for breeding. The next shipment was sent from Algeria and arrived late in March 1899. From this the *Blastophaga* was established in the Roeding fig grove, and the successful growing of the Smyrna type fig in California was assured. At the present time, out of an average total dried fig output of about 12,000 tons, the Adriatic variety represents 60 percent, the Mission 15 to 20 percent, and the balance is of the Smyrna type. The decline in the popularity of the Smyrna type fig despite its admittedly high quality when well grown is due mainly to fruit splitting and souring. It is obvious that there is need for breeding new Smyrna type varieties of good quality without the present defects.

The most important canning variety, Kadota (synonymous with Dattato and White Endich), originated in Italy (*16*). The tree is vigorous and productive. The small size, tough skin, seedlessness, and low proportion of pulp rule it out as a drying fig, but on the whole,

in spite of deficient flavor, it is an acceptable canning variety. The tree, however, is subject to injury from red mite, and the culls run high on account of wind scarring, eye cracking, sunburn, and mildew.

The production of California canned figs, which come into competition with the Texas product, reached a peak in 1930 with more than 250,000 cases (about 4,000 tons) of the Kadota; this dropped in 1931 to about one-third of the previous year's production and increased to more than 140,000 cases in 1932.

Owing to their perishable nature, the cost of handling fresh figs on the retail market is considerably higher than that of other fresh fruits, and competition with other fruits has cut down the financial returns to a point where this industry in California has had little encouragement. The shipments, which are mostly of the Smyrna (Calimyrna) and Mission types, average about 100 cars a year.

The fig industry attained commercial importance in the Gulf coast region of Texas between 1901 and 1906 in Galveston County. The industry is based on one variety, Magnolia, of the Adriatic type (*126*), which is utilized primarily for canning. The commercial area is confined largely to the humid section of the Gulf coast prairie, extending from the Louisiana line to Jackson and Matagorda Counties and inland from the coast approximately 50 miles.

The Magnolia variety is preferred by the packers largely because of the attractive appearance of the processed fruit. Unfortunately the fruit is carried upright on the branch and at the same time has a more open "eye" than some other varieties, which probably accounts for its tendency to sour readily, especially during damp weather (*110*). Some varieties, such as Celeste and Allison, when grown under Texas conditions have a more leathery skin then the Magnolia and will dry on the tree to some extent without souring. Picking may be delayed with such varieties for a few days without loss of fruit. The fruits of the Celeste and Green Ischia varieties turn downward when ripe, thereby lessening the chance of souring. Another variety, Gentile, of the White San Pedro type, although somewhat lacking in flavor, has an apparent advantage over the Magnolia variety in that the blossom end turns downward when the fruit matures. Such a variety should prove valuable in a breeding program calculated to overcome the chief defect of the Magnolia variety.

In Florida, where nematode infection is a serious limitation on fig growing, Mowry (*70*) has attempted to utilize a nematode-resistant stock for grafting to such varieties as Celeste, Brunswick, and Green Ischia. While grafts have been successfully made on several species of *Ficus* (as *F. glomerata* Roxbg. and *Ficus* sp., P. I. 52406), the practical results are still in doubt. Good unions are apparently obtained and the initial growth appears normal, but the later development is generally unsatisfactory. Green Ischia is reported to have given the best results of the scion varieties used. The late E. N. Reasoner [3] tried out the native species *F. aurea* Nutt. and *F. brevifolia* Nutt. as stock about 1900, with even less success. Among the extremely numerous species of *Ficus* still untested, it is quite possible that a satisfactory stock might eventually be found or developed by breeding methods.

[3] Unpublished work.

Present Work on Fig Breeding in the United States

Where caprifigs are not locally available, the pollen-bearing fruits of the spring crop (profichi) when approaching maturity may be secured from distant regions and successfully used for cross-pollinations. Wrapping the caprifigs in tinfoil or similar material to prevent drying out, as was done by Swingle, according to Howard (*42*), is an important aid in prolonging the life of the *Blastophaga*. This was the method used by Hunt and others in securing pollen for hybridization.

The physiology of fig pollen has apparently not been studied in detail. Such subjects as the duration of pistil receptivity and the possibility of storing the caprifig with mature pollen for use when needed in breeding work under controlled low-temperature and favorable humidity conditions have not been investigated.

Most of the available fig varieties have been secured by mass selection of chance seedlings, but this method has little or no application in the modern breeding program. The most promising method of attack seems to be cross-pollination of desirable parent varieties, followed by selection within the first generation and backcrossing on the parent or outcrossing on other desirable varieties to secure the desired recombination of characters.

Figure 2.—Ira J. Condit, who has been engaged in subtropical fruit research at the California Agricultural Experiment Station since 1913, with special interest in the fig; has made important contributions to the cytology and genetics of the fig; is actively engaged in fig breeding.

Mutations in *Ficus carica* apparently are not frequent, and the procedure of bud selection apparently offers little promise. Collins in 1919 and Condit (*18*) have reported chimeras and variegation in *F. carica*. Such types as have been observed are of doubtful value in fig culture. Application of methods for stimulation of mutations by X-rays, heat treatments, or by inducing tumorous growths might yield results of value.

An extensive fig-breeding project is being carried on at the University of California Citrus Experiment Station at Riverside under the leadership of Ira J. Condit (fig. 2). The objectives are to obtain a white fig for drying as good as the Mission, a good white fig resistant to insect infestation, and figs resistant or immune to fruit-spoilage diseases. On account of the peculiar structure of the fig and its more or less open eye, this fruit type is more susceptible to infestation by insects and the fungi they carry than other fruits. The plan also includes the development of better common figs that do not require caprification. Should the grower desire to caprify his crop, and thus improve the quality of the dried product, he can do so. The Cali-

fornia breeding collection contains 140 varieties and species and includes most of the varieties introduced by the Division of Plant Exploration and Introduction, Bureau of Plant Industry.

The varieties of special importance in the California collection are the following:

Brawley.—Said to be a hybrid between Kadota and *Ficus pseudocarica*, valuable for earliness and for vigor.

Brown Turkey.—The largest-fruited common fig now grown.

Lob Ingir (Calimyrna).—The standard for quality, both fresh and dried.

Excelsior.—The largest caprifig in the collection.

Ficus palmata.—The earliest caprifig in the collection.

Ficus pseudocarica.—Used by Rixford and Swingle in hybridizing figs many years ago and apparently good for possible hybrid vigor.

Kadota.—An excellent fig for use fresh, and very prolific.

Mission.—An excellent black fig, but figs of the second crop are too small.

Partridge Eye.—A fig with an unusually small eye, a characteristic that, it is hoped, can be transmitted to offspring.

Roeding No. 3 and Stanford.—Two standard varieties of caprifigs in California, the first with purple flowers, the second with white flowers.

Hybridization of figs was begun at Riverside by Condit in 1922. Up to November 1936, 3,855 seedlings have fruited, of which 1,914, or 49.6 percent, are of the caprifig type and 1,941, or 50.4 percent, produce edible figs. A few caprifigs have been saved for future trials, but most of them have been discarded. A number of edible fig varieties having desirable characteristics have been found and much valuable information has been secured about the inheritance of characters in the fig. Table 1 gives a numerical summary of Condit's important work.

TABLE 1.—*Summary of fig-breeding work at Citrus Experiment Station, Riverside, Calif., 1922–36*

Class and parentage	Trees	Total trees fruited		Trees not fruited	Trees marked promising	
		Caprifigs	Edible figs		Caprifigs	Edible figs
Lots of seedlings that have practically all fruited:	*Number*	*Number*	*Number*	*Number*	*Number*	*Number*
Seedlings of known parentage, fruiting for several years	1,082	519	543	20	12	27
Seedlings of unknown parentage, fruiting for several years	2,209	1,106	1,037	66	13	17
Seedlings of more recent fruiting, of known parentage	289	162	116	11	7	6
Total	3,580	1,787	1,696	97	32	50
Seedlings fruiting for first season (1936), if at all, parentage specified:						
Kadota × Stanford	33	5	10	18		
Kadota × Brawley	84	13	32	39		
Kadota × *Ficus pseudocarica*	66	13	26	27		
Kadota × 2–21	14	0	8	6		
Kadota × 3–19 (3 = Kadota × *F. palmata*)	29	9	15	5		
5–117 × 5–95 (5 = Kadota × R.3)	70	3	25	42		
2–22 × 2–21 (2 = Kadota × Kearney)	15	1	1	13		
Partridge Eye × Stanford	48	7	14	27		
Partridge Eye × Brawley	20	4	6	10		
Hamma × *F. palmata*	68	24	28	16		
F. pseudocarica × Roeding 3	70	2	18	50		
Mission × 8–12	69	27	31	11		
8–1 × 8–12 (8 = Mission × Kearney)	72	7	5	60		
Marabout × "Capri misc."	39	0	0	39		
Palmata × Roeding 3	50	9	23	18		
Violette Sepor × "Capri misc."	71	2	3	66		
Total	818	127	245	446		
Grand total	4,398	1,914	1,941	543		

The precocity shown in seedlings of progenies of Hamma × *Ficus palmata* and *F. pseudocarica* × Roeding 3 is outstanding. Condit reports that some individuals have produced fruit during the same season in which the bud was inserted in the large tree. His conclusions as to inheritance, based on this work, will be given in the section on genetic research.

The Texas Agricultural Experiment Station, in cooperation with the United States Department of Agriculture, has brought together at Substation No. 3 at Angleton an extensive fig variety collection. It includes 131 separate items, including the varieties introduced by the Department and the most valuable varieties singled out by the early fig breeders or produced by their breeding efforts.

The varieties of special merit that are being used by S. H. Yarnell and H. M. Reed in breeding work at Angleton are the Magnolia, Excelsior, Allison, Celeste, and Green Ischia. Hybridization work was started in 1935, and the crosses made include Magnolia × Excelsior and Allison × Excelsior. Magnolia, Allison, and Green Ischia have been crossed with an unnamed caprifig. The chief objects are to secure improved types of canning and fresh shipping figs and also an improved type for the home garden. The chief characters being recorded are vigor, time of harvest, size of fruit, size of eye, firmness of fruit, flavor, position of fruit on its stem, and productiveness.

Fig Breeding in Foreign Countries

At the Superior School of Agriculture, Laboratory of Horticulture, Athens, Greece, P. Th. Anagnostopoulos has assembled a fig collection and the material is being studied for the selection of superior varieties, especially those of value in drying.

At the Imperial Horticultural Station, Okitsu, Japan, under the direction of T. Tanikawa, acting director of fig-breeding work, consisting of hybridization followed by backcrossing, was begun in 1915. The backcrosses were undertaken in 1924. Pollen was transferred in a manner similar to the method used by Hunt in Georgia without the aid of *Blastophaga*. Roeding No. 2 (caprifig) pollen was used on White Adriatic, White San Pedro, and Hative d'Argenteuil. Some of the first-generation progeny bear edible fruit. Two first-generation hybrids of the White San Pedro type, designated *A* and *B*, were chosen for further crossing; the former was crossed on White San Pedro and the latter on Hative d'Argenteuil. The progeny from these crosses have now come into bearing. At least 20 are promising and are being intensively studied in comparison with the other varieties in the collection.

In Mexico the principal varieties under cultivation are Mission and White Adriatic, the main crop maturing from August to October. An attempt is being made to introduce the Smyrna fig and the fig wasp necessary for the pollination of this type of fig.

O. S. H. Reinecke, head of the department of pomology, College of Agriculture, University of Stellenbosch, Union of South Africa, reports that figs are included in their variety trials.

Cytology and Genetics of the Fig [4]

The cytology of the genus *Ficus* has received attention from Condit (*20*) and Kraus (*55*). The chromosome numbers have been determined for 17 species, and the data have been summarized in table 5 of the appendix. In most cases the haploid number is reported as 13 or "probably" 13. Condit reported the diploid number of *F. glomerata* as probably 24, and Kraus the haploid numbers of *F. quercifolia* Roxb. and *F. repens* Hort. as probably 14. The chromosome number of *F. roxburghi* has apparently not been determined.

The following is a summary of Condit's tentative conclusions on inheritance, based on the work in California to date:

> When the edible fig, purely pistillate (monoclinous) is crossed with the caprifig which has pistillate and staminate flowers in the same receptacle (diclinous), the progeny is divided about half and half between the two parent types in sex expression.
>
> When two large-fruited fig varieties are crossed (Dauphine × Excelsior), the progeny is about half large-fruited and half medium-fruited. Only a minor percentage is small-fruited. On the other hand, if a medium-fruited variety is crossed with a small-fruited one (Kadota × *Ficus palmata*), the progeny is about half medium and half small, with no large-fruited individuals. When a medium-sized variety is crossed with a large variety (Kadota × Roeding 3), the greater percentage (over 80 percent) is of medium size, with the remainder divided equally between large and small.
>
> Black color of skin is dominant over yellow or green (Mission × Kearney), and yellow over green.
>
> Internal color—usually purple—of caprifigs is generally dominant over amber or white (colorless) in seedling caprifigs of a cross. Internal color of edible figs appears to be dominant over ambers and white in some variety crosses and not in others.
>
> Earliness in maturity is dominant over lateness and can be readily transmitted to the progeny by early caprifigs such as *Ficus palmata*.
>
> In general, color of buds other than green is dominant over green. It appears that some varieties are heterozygous for terminal bud color.
>
> Inheritance of parthenocarpy (fruit development without pollination) has not been studied in detail. It appears to be recessive in Smyrna figs, as well as in some caprifigs, such as *Ficus palmata*.
>
> Certain leaf and twig characters are dominant over others in some crosses—for example, nonlobed leaf over lobed leaf, and reddish-brown pubescence of twigs over green pubescence in *F. palmata* caprifigs.

AVOCADO

The avocado is native to Central America and Mexico. Long before the discovery of the Americas it was an important food crop in these regions and also in the northern Andes of South America and the coastal region of the Gulf of Mexico and the Caribbean Isles. The nourishing and appetizing avocado fruits are cheaply produced in tropical America, and they serve in a measure as a meat substitute. Avocado culture has now spread to other regions. The most outstanding developments in commercial culture have taken place in the United States, where thriving industries have been established in California and Florida.

Various names have been applied to this fruit crop, including the inelegant term "alligator pear", but the correct term in English is

[4] This section is written primarily for students and others professionally interested in breeding or genetics.

avocado, a name used as early as 1696, undoubtedly a corruption of the Spanish "ahuacate" or "aguacate", which was adapted from the Aztec "ahuacatl" (*91*).

The cultivated avocado varieties are all included in one species, *Persea americana* Mill. (*P. gratissima* Gaertn.). At one time it was supposed that two species were represented, but this proved not to hold in the light of later investigations (*92*). Within the species three general ecological races are recognized that present distinctions of importance horticulturally. The West Indian or lowland race is most susceptible to injury from cold and matures its fruits in summer and fall. The fruits are low in oil content, and intermediate in the thickness of the leathery skin between the highland Guatemalan and Mexican races. The latter races are relatively more resistant to low temperature, the Mexican race being the more hardy of the two. The fruits of the Guatemalan race, maturing in winter and spring, have a thick, woody skin and an intermediate oil content. The Mexican race, maturing in the summer, has a very thin skin and a high oil content. The coyo, *P. schiedeana* Nees, native to Guatemala and closely related to the avocado, has not proved of value in cultivation.

Introduction Into the United States and Hawaii

In all probability the avocado was brought to Florida by the early settlers, but the first recorded introduction was in 1833, when Henry Perrine sent trees from Mexico to be planted on his government land grant south of Miami (*83*). Only isolated plantings were made in Florida until 1900, when the first avocado nursery was established at Miami by George B. Cellon. The interest in the crop increased after that date, and many plantings have since been made. The late W. J. Krome and other pioneer growers in southern Florida have tested out a great many varieties from California, Central America, and Mexico, including the Department introductions. A number of groves have also been planted in other parts of the State, notably on the east coast in the Fort Myers district and in the south-central ridge section, where Ivey Futch, of Lake Placid, W. F. Ward, of Avon Park, and others have established successful groves. Smaller plantings are found as far north as Orange County.

Avocado seeds of the West Indian and Guatemalan races reached Hawaii from Central America before 1825. Owing to the lack of an outside market, the Hawaiian industry is being developed on a scale to supply local needs only.

In the lower Rio Grande Valley of Texas seedling introductions of the Mexican race from Mexico have survived in dooryards in a number of instances. Horne (*41*) points out that the Mexican varieties are the most promising for this section, although they should be planted only on an experimental scale. The avocado apparently was introduced successfully into California in 1871, when R. B. Ord secured trees from Mexico, which he planted at Santa Barbara (*39*). J. C. Harvey, Jacob Miller, and Juan Murrieta, of Los Angeles, F. Franceschi, of Santa Barbara, and C. P. Taft, of Orange, were other early avocado growers in California who introduced trees from abroad or produced new varieties from seeds. F. O. Popenoe (fig. 3, *A*) and

T. V. Barber, of Altadena, imported budwood of Mexican varieties in 1911–12, and among these the Fuerte and Puebla are outstanding. E. E. Knight, of Yorba Linda, imported and introduced the two Guatemalan varieties, Queen and Linda, while Joseph Sexton, of Goleta, was interested in the varieties of the West Indian race and in Hawaiian varieties. Sexton's experiments were valuable for the

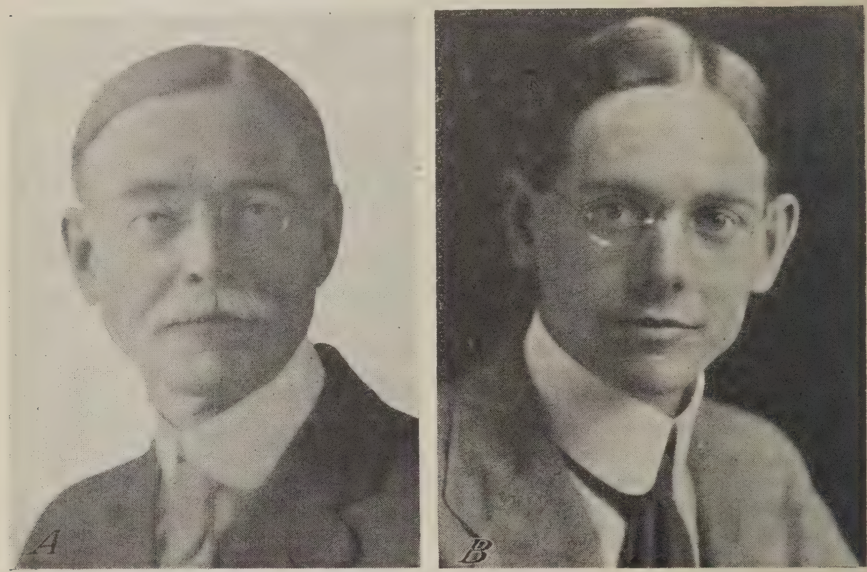

Figure 3.—Popenoe, father and son. *A*, F. O. Popenoe (1863–1934), who introduced and distributed, through the West India Gardens, Altadena, Calif., the Fuerte and Puebla varieties of avocado, which made up 80 to 90 percent of all commercial plantings in California during the last decade. *B*, Wilson Popenoe, agricultural explorer for the United States Department of Agriculture, 1913–25; introduced germ-plasm collection of avocado and its relatives from Mexico, Central America, and South America; also collected annonas, sapotas, and other subtropical and tropical fruits. Since 1925, as director of research for the United Fruit Co., he has assembled at Tela, Honduras, extensive germ-plasm collections of tropical and subtropical fruits and other crop plants.

industry as a whole, for they demonstrated that the West Indian varieties are not adapted to California conditions.

The avocado collections made by private individuals in the United States were further enriched by the importation of many varieties from Mexico, Central America, and South America by the Department of Agriculture, beginning in 1906. Cook and Collins began the importation of varieties from Guatemala, and the work was completed by the thorough explorations of Wilson Popenoe (fig. 3, *B*), 1916–21, in Guatemala and other Central American habitats as well as the northern Andes of South America (*89*). As a result of the systematic search by Wilson Popenoe, an abundance of worth-while Guatemalan avocado germ plasm was introduced into the United States and made available to plant breeders in other countries as well.

Wilson Popenoe made selections on the basis of desirable characters with special reference to hardiness, early and late fruit maturity, proportion of edible material, and excellent dessert quality. The varieties selected include the whole range of fruit shape, size, and rind color. The following 28 Guatemalan varieties were introduced on this basis for trial in California and Florida: Lamat (P. I. 43476), Kanola (P. I. 43560), Ishkal (P. I. 43602), Coban (P. I. 43932), Kashlan (P. I. 43934), Chisoy (P. I. 43935), Pankay (P. I. 44785), Nabal (P. I. 44439), Nimlioh (P. I. 44440), Panchoy (P. I. 44625), Tumin (P. I. 44627), Benik (P. I. 44626), Kekchi (P. I. 44679), Mayapan (P. I. 44680), Kayab (P. I. 44681), Manik (P. I. 45560), Cabnal (P. I. 44782), Cantel (P. I. 44783), Tertoh (P. I. 44856), Akbal (P. I. 45505), Ishim (P. I. 45562), Kanan (P. I. 45563), Chabil (P. I. 45564), Itzamna (P. I. 43486), Batab (P. I. 43487), Chilan (P. I. 43933), Hunapuh (P. I. 44628), and Tamayo (P. I. 53182). Of the Mexican race, Capec (P. I. 54276), Chota (P. I. 53184), Egas (P. I. 53183), and Kaguah (P. I. 45561) were introduced.

One promising source of avocado germ plasm, the Mexican highlands, where the Mexican type of avocado has been cultivated since pre-Columbian times, has not been exhaustively explored.

This germ-plasm collection contains several varieties, notably Nabal, Benik, Itzamna, and Nimlioh (in California), that give promise of immediate utility in culture, but its main value is for cross breeding to obtain combinations of resistance to low temperature, high quality, long range in marketing season, and other desirable characters represented in the varieties.

Progress in Avocado Improvement

It is highly satisfying to contemplate the future of the avocado industry from the standpoint of the improvement of varieties by plant breeding. The industry has had the benefit of superior varieties from the beginning, and in addition the breeder has for his use a most comprehensive collection of avocado germ plasm, which contains types very resistant to low temperature and characterized by other desirable traits to be combined with the fruit qualities demanded by the market. Fortunately, this germ-plasm collection has been brought in during the early stages of the industry by the foresight and energy of the early pioneers, and later by Wilson Popenoe, then of the Department. The thorough manner in which the work has been done by Popenoe may be gaged in some measure by noting the total of 287 separate avocado (*Persea americana*) introductions, and 62 separate introductions within species related to it.

California

The commercial avocado industry in California is concentrated largely in southern California, and the most important producing districts are in the coastal region extending from San Diego to Santa Barbara, including portions of San Diego, Los Angeles, Ventura, and Santa Barbara Counties, and all of Orange County. Commercial avocado groves have also been planted farther inland in protected locations on the foothill slopes of the Santa Paula, San Fernando, San Gabriel, and Santa Ana Valleys. On the whole, therefore, the

avocado plantings are mostly located in the milder sections of the citrus area. The industry in California is at present founded almost entirely on one variety, the Fuerte, which fulfills the market preference

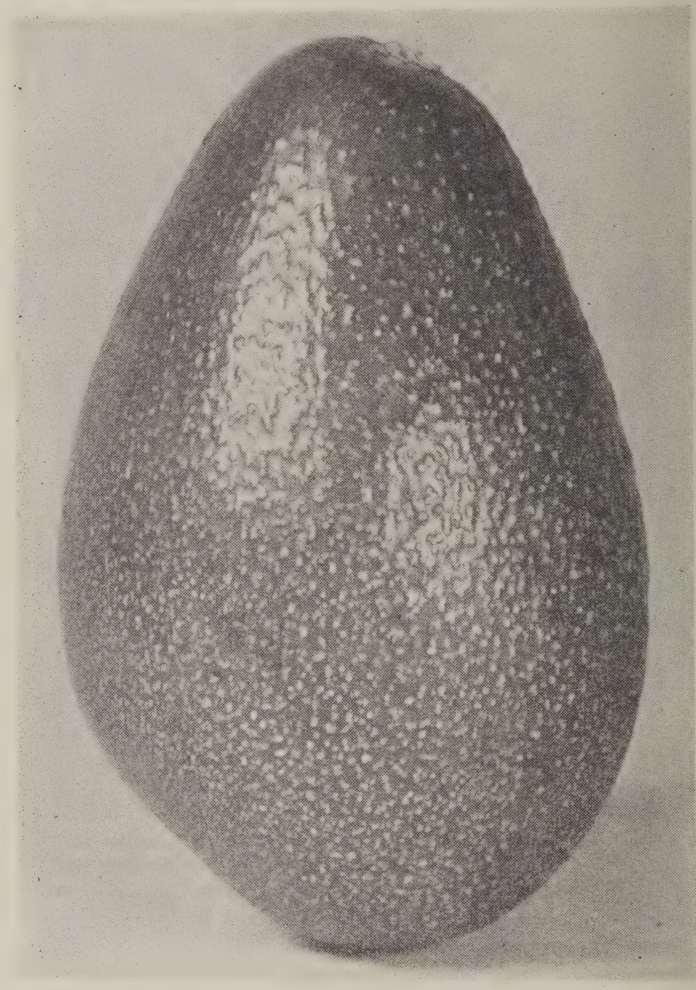

Figure 4.—Typical fruit of the Fuerte avocado—reputed to be a natural hybrid of Guatemalan × Mexican origin; almost ideally adapted to market requirements as to size, color, long season of maturity, and hardiness, under California conditions; not adapted to Florida.

for a medium-sized fruit weighing from 8 to 14 ounces, maturing mainly during winter and spring, December to June, but with some ripe fruits available practically every month of the year (fig. 4). The Fuerte variety was introduced into California in 1911 from Atlixco, State of Puebla, Mexico, where the original tree is still in a thriving condition (fig. 5). Under California conditions the trees have proved to be

highly resistant to low temperature, vigorous in growth, and fairly productive. The Fuerte is assumed to be a natural hybrid between the Guatemalan and Mexican races. A series of seedlings of the Fuerte grown about 1920 at the plant introduction garden of the Department at Buena Vista, Fla., showed segregation for anise odor of leaves, individuals occurring both with and without this odor. This lends confirmation to the hypothesis of hybrid origin, although

Figure 5.—The original Fuerte avocado tree, a seedling tree growing near Atlixco, Mexico; considered a hybrid between Guatemalan and Mexican races. Approximately 90 percent of the trees in commercial avocado groves in California are of this variety.

cross-pollination from different sources may have affected the resulting progeny.

Another variety, Puebla, also introduced from Atlixco in 1911, is second in importance. It is of the Mexican race, highly frost-resistant, a vigorous grower, maturing in California from December to February, which is later than most varieties of the Mexican race. Other varieties such as the Nabal, Queen, Taft, Anaheim, Dickinson, and Mayapan are also recommended by the California Avocado Growers Association for planting.

The selection of new varieties from the numerous introductions and from local seedlings was begun under the direction of Hodgson and his coworkers at the southern branch of the University of California at Los Angeles in 1931, but artificial hybridization has not yet been undertaken.

Florida

In the early history of the avocado industry in Florida the early-maturing varieties were grown, mostly of the West Indian race, but Cuban competition in the summer and fall seasons has forced growers

to extend their marketing season by the use of fall and winter varieties of the Guatemalan race and hybrids. The leading varieties for planting at present are Waldin, Trapp, Fuchsia (West Indian race); Taylor, Wagner, and Itzamna (Guatemalan race); and Collinson and Lula (hybrids). Many of the varieties planted earlier have been discarded, and there is a tendency toward the planting of fewer varieties. Even the best varieties have obvious defects, and the final work has not yet been done in varietal selection. The varieties cultivated in Florida have been described in detail by Toy (*124*), Stahl (*109*), and Wolfe, Toy, and Stahl (*137*).

In the chief center of avocado production in Florida—Dade County—the early to midseason varieties are of the West Indian race. In central Florida the early maturing varieties are of the Mexican race or its hybrids. The varieties of the West Indian race are characterized by relatively low oil content of the fruit and maturity seasons ranging from summer to late fall. The varieties of the Mexican race have a relatively high oil content and under Florida conditions are usually early in maturity.

The earliest maturing variety, Fuchsia, originated by C. T. Fuchs, Sr., Homestead, Fla., as a chance seedling, was introduced in 1926. It is apparently of the West Indian race. The tree is vigorous and productive, and the fruit matures from June to August in Florida. This variety is suitable for southern Florida, particularly Dade County.

The other early variety, Gottfried, is apparently a hybrid between the Mexican and West Indian races, since seedlings from trees in isolated locations show segregation for anise-scented and non-anise-scented individuals. It originated at the United States Plant Introduction Garden, Miami, in 1906 from a seed collected on the premises of Edward Gottfried, Key Largo, Fla., and was introduced in 1918. This variety is very resistant to low temperature and is exceedingly vigorous and productive in Orange County, where it is grown for local market, but it is not adapted to southern Florida. The maturity season ranges from June to September.

The Trapp variety (fig. 6, *A*) was the first named variety to be introduced in Florida, and it is still being planted in spite of the fact that it is a rather weak grower, owing in part to its tendency to overbear, and is susceptible to insect and disease injury. The fruit matures from September to November. It originated as a chance seedling grown by H. A. Trapp, of Coconut Grove, and was introduced in 1901 (fig. 7). It is outstanding in historical interest, as it was the first-named variety of the avocado to be propagated vegetatively in Florida. This was done by George B. Cellon, of Miami.

The Peterson variety was introduced in 1928 by Peter Peterson, of Modello. The fruit resembles that of the Trapp but averages smaller in size and is more attractive in color. It matures from the middle of September to the middle of November.

The Waldin variety, originated by B. A. Waldin at Homestead, was introduced in 1917. The fruit matures from October to December in Florida. This is one of the outstanding varieties for planting in Dade County.

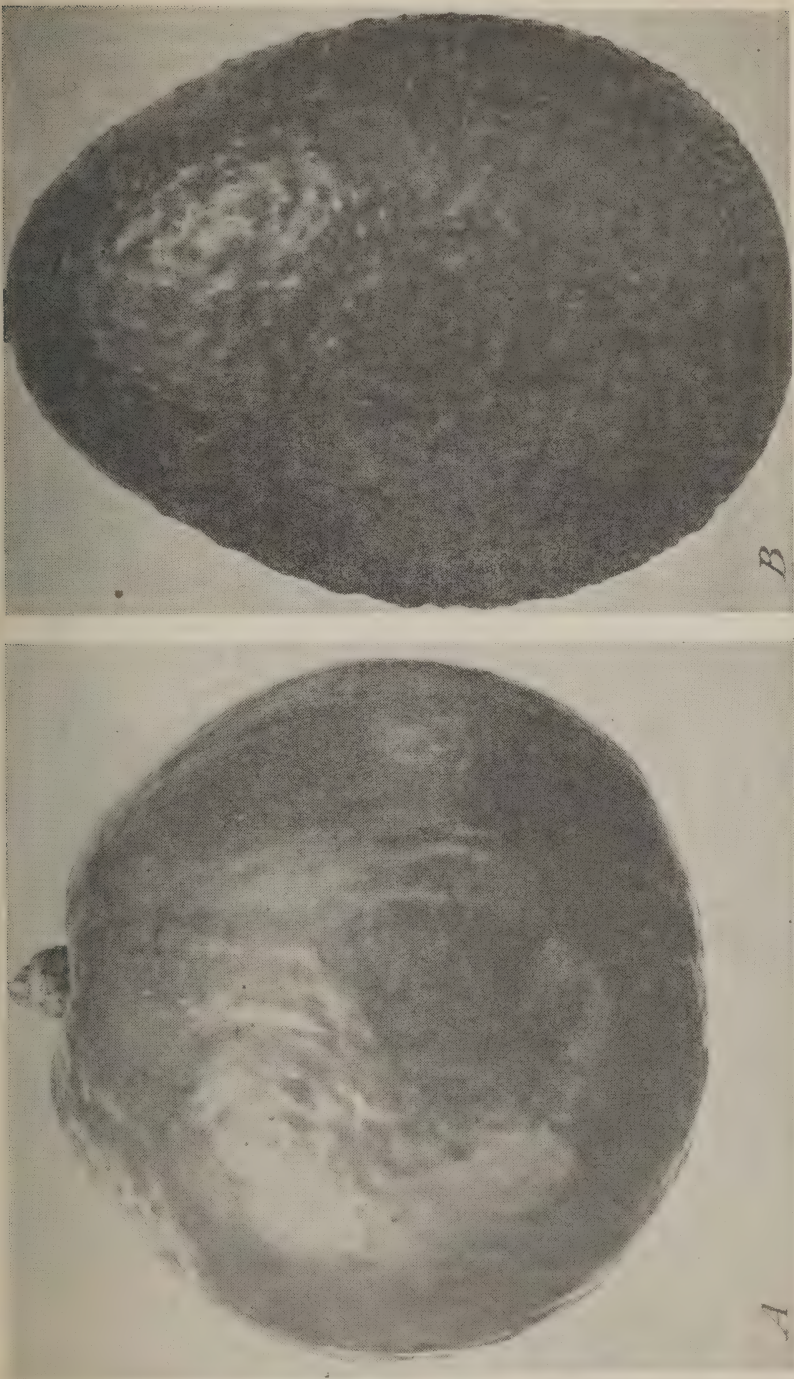

Figure 6.—*A*, Fruit of Trapp avocado. The Trapp was the first avocado variety propagated vegetatively in Florida. Its high quality and medium size have contributed to its continued popularity. *B*, The Taylor avocado. Its hardiness, small size, regular bearing habit, and winter season of maturity in Florida have contributed to the commercial importance of this variety.

The improvement of the summer and fall varieties has been arrested on account of Cuban competition, and this has stimulated efforts to produce later-maturing varieties. In general these fall into two classes from the genetic standpoint—varieties of the Guatemalan race and hybrids.

Among the varieties of the Guatemalan race, Taylor and Wagner are outstanding. Taylor originated at the United States Plant Introduction Garden at Coconut Grove as a seedling of Royal and was introduced in 1914 (figs. 6, *B*, and 8). The fruit matures from the middle of December to the middle of February. It was one of the first Guatemalan varieties to be planted commercially, and it has not lost its popularity. Its tall, slender growth habit is objectionable. The Wagner variety, also a seedling of Royal, originated by C. F. Wagner, of Hollywood, Calif., and introduced in 1914, is similar to Taylor, but the season of maturity is somewhat later (Jan. 15 to Mar. 1), and the fruits are rounder in form. The Taylor and Wagner varieties are adapted to southern and central Florida.

The Itzamna variety is a direct introduction from Guatemala, made by the Department in 1916 and distributed in 1923. The fruits mature from February 15 to April 15. On the basis of its performance so far it is being planted in southern Florida.

The group of interracial hybrids is the most interesting from the breeding standpoint, since it gives some evidence as to what may be expected by the application of breeding methods. The hybrids so far introduced are the result of open pollination. They show hybrid vigor and as a rule are better adapted to local conditions than representatives of the races introduced directly from abroad. The most promising natural hybrids so far introduced show Guatemalan-West Indian or Guatemalan-Mexican characteristics in combination.

The Collinson variety, originated at the Plant Introduction Garden at Coconut Grove, from a Collins seed, was introduced in 1920 and has met with popular favor. It appears to be a Guatemalan-West Indian hybrid and is highly resistant to scab. The season of maturity is from November 15 to February. It is adapted to southern and central Florida.

The Fuerte, the chief variety grown in California, is not adapted to Florida conditions. Apparently it is a natural Guatemalan × Mexican hybrid, introduced from Mexico. However, the Lula, originated by George B. Cellon at Miami from a seed of the Taft variety and introduced in 1921, shows evidence of Guatemalan-Mexican parentage and is an outstanding variety in Florida, in spite of its high degree of susceptibility to scab. The season of maturity is from December to February.

The outstanding varieties of recent introduction are the Booth seedlings, which originated in Dade County from Guatemalan seeds gathered in a grove interplanted with trees of the Trapp and Waldin, both varieties of the West Indian race. Selections have been made so as to secure a wide range in maturity periods—Booth No. 8, November; Booth No. 7, December; and Booth No. 3, January.

The Dunedin variety, originated by L. B. Skinner at Dunedin, Fla., is a seedling of the Winslow, the original seed coming from the Plant Introduction Garden at Miami. The tree is evidently a Guatemalan-

Figure 7.—Parent tree of the Trapp avocado. Originated as a seedling of the West Indian race; parent tree grown by H. A. Trapp, of Coconut Grove, Fla.; first fruiting about 1898. Propagated by George B. Cellon and introduced in 1901 for commercial planting; the first named variety of avocado. The original trunk is shown, but the top of the tree was broken off near where Mrs. Trapp has her hand, and the present top is a relatively recent (10 years old) outgrowth from the stump.

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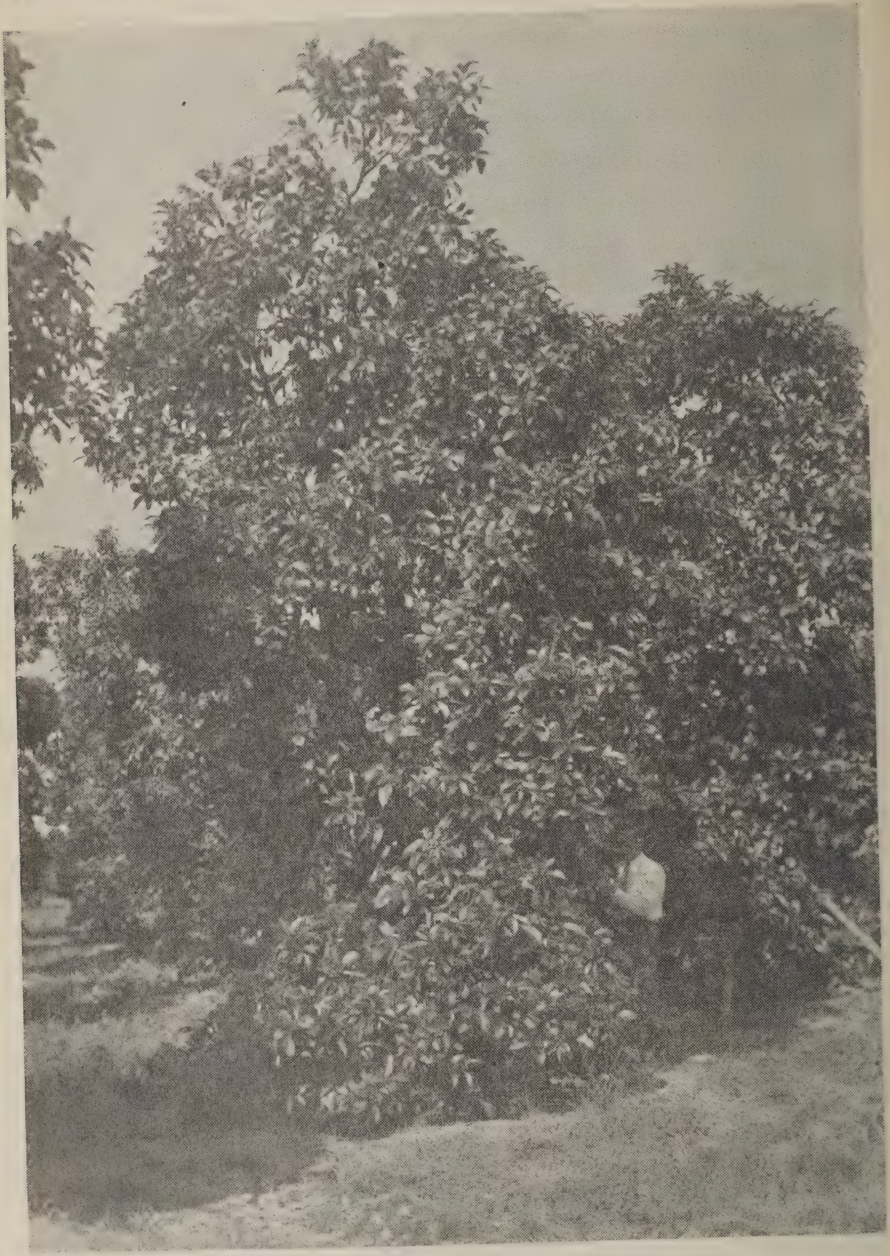

Figure 8.—Taylor avocado tree, growing in Dade County, Fla., showing typical upright habit. This variety originated as a seedling of the Royal, planted in 1907 at the United States Plant Introduction Garden at Miami, Fla.; first fruited in 1913; propagated for commercial planting in 1914. The leading variety of the Guatemalan race for Florida planting.

West Indian hybrid like the Winslowson, but is more hardy than the latter and holds its fruit later into winter. The fruit is of excellent quality and medium size, and the tree is a vigorous grower.

The variety named Fairchild in honor of David Fairchild was introduced in 1933. It is a first-generation progeny of Collinred, a Collinson sister seedling, originated at the Plant Introduction Garden at Coconut Grove. The fruit is characterized by a red blush. The variety has not been extensively tested.

Philippine Islands

Avocado improvement was begun in the Philippine Islands by the late P. J. Wester, who introduced many varieties from the United States early in the twentieth century. The work is now being continued by J. P. Torres, F. G. Galang, and E. K. Morada and is concerned chiefly with intensive study of the introduced varieties and locally produced seedlings. The breeding method used is that of mass selection. The existing varieties are being classified as to their flowering and fruiting habit and other important tree and fruit characters.

Although imported varieties such as Cardinal and Pollock and local varieties such as Suarez, Lopena, and Batangas No. 2 have been distributed for commercial planting, the greater part of the trees planted are miscellaneous seedlings (*22*).

Foreign Countries

In the foreign countries where avocados are grown commercially the industry as a rule is based on varieties introduced from the United States.

In the West Indies, Cuba, and the British possessions avocado industries are based primarily on miscellaneous seedling trees. In Cuba one variety of the West Indian race, Somerford (Catalina), has been introduced. In Trinidad, Pollock is grown, but most of the trees planted are seedlings.

G. Gandara, of the Mexican Department of Agriculture, reports that in Mexico the avocado is an important product, the annual commercial production being estimated at 63 million pounds. The main season of the crop is in the summer and autumn months. The types grown are largely seedlings ranging from rough fruits with thick rind of many shapes and sizes to smooth fruits with thin skin. Colors vary from green to dark purple. The type predominating in Chiapas is large, green or yellow like the Nimlioh of Guatemala. In Queretaro the Mexican type with smooth rind and anise-scented leaves predominates. The experiment stations where selection work is in progress are at Queretaro, Queretaro; Acapulco, Guerrero; Leon, Guanajuato; Hocelchacan, Campeche; and Oaxaca, Oaxaca. Selection is being made of types better suited to commercial propagation and if possible resistant to attack by the weevil *Heilipus lauri* Boh.

In Brazil, Jaoa Dierberger, Jr., of São Paulo, has introduced the outstanding American varieties, and these have now been tested out for some years. On the basis of these tests different groups of varieties are recommended for the highlands in the section of São Paulo and the lowlands around Santos.

In Queensland, Australia, the American varieties have been introduced and are under test by the Queensland Acclimatisation Society at Brisbane.

J. A. Campbell, director of the division of horticulture, New Zealand Department of Agriculture, Wellington, reports that some progress has been made in the introduction of avocado varieties.

For the Union of South Africa and Rhodesia, Blatt (*5*) recommends that 50 percent of any commercial planting should be Fuerte and that the remainder should include wholly or in part Nabal, Puebla, Taft, Queen, Mayapan, Dickinson, and Anaheim.

Objectives and Methods in Avocado Breeding

The application of scientific breeding methods to the improvement of the avocado has only begun, and the major achievement up to the present time is the introduction of an extensive germ-plasm collection, which contains most of the valuable material nature has provided. The varieties available are being intensively studied in both California and Florida. A comprehensive collection has been assembled by Hodgson and his coworkers at the southern branch of the University of California at Los Angeles; in Florida variety collections are maintained at the Florida State Subtropical Experiment Station at Homestead by Wolfe and his coworkers, and at the Plant Introduction Garden at Coconut Grove, under the leadership of T. B. McClelland.

The ideals to be sought in avocado breeding vary somewhat with the various production regions, as would be expected. In 1920 Krome (*57*) outlined the requirements for an ideal commercial avocado variety for Florida—(1) compact tree growth; (2) a regular fruiting habit; (3) season of maturity best suited to market demand, fall or winter; (4) color of fruit, green when mature; (5) size medium, averaging from 1 to 1½ pounds; (6) shape round, oblate, or slightly oblong, without pronounced neck; (7) freedom from fiber; (8) good flavor and oil content; (9) seed small to medium-sized. To these requirements the following additions or amendments might now be made: (1) Resistance to diseases affecting foliage, fruit, and stem, chiefly scab and cercospora spot; (2) resistance to cold injury; (3) size of fruit from 10 to 16 ounces; (4) smooth or only slightly corrugated skin, thin to medium in thickness; (5) smooth, creamy pulp, free from soapy or insipid flavor, with oil content at least 6 percent, preferably higher; and (6) seed tight in cavity with seed coat adhering to seed.

An objective particularly important from the standpoint of marketing and grove cultural requirements should be emphasized. On account of the necessity for interplanting varieties of the A and B flowering groups, to be discussed later, it would be highly desirable to produce varieties with quite similar fruiting characters in each of these groups. Ivey Futch, at Lake Placid, Fla., has grown a seedling (B group) from Lula (A group) which is fairly similar to the parent variety and in addition is less subject to scab.

In California regular bearing habit and season of maturity are the characters that need most attention in improvement breeding, since at least three varieties, Fuerte, Nabal, and Taft, are now ranked as excellent in quality and satisfactory with regard to attractiveness and marketability of the fruit. Varieties similar to Fuerte, with regular

bearing habit and maturing fruits at different seasons, are needed. The ideal avocado fruit from the standpoint of marketing, according to the variety committee of the California Avocado Growers Association, is described as follows: (1) Size, 6 to 12 ounces; (2) shape, typically pyriform (pear-shaped); (3) color, dark green; (4) seed, less than 12 percent of fruit, tight, with seed coats adhering to seed; (5) skin, medium thin, tough, with smooth surface, yielding when softening; (6) flesh, oil content 16 to 22 percent, free from fiber, deep yellowish green; (7) flavor, rich and nutty, free from sweetness, bitterness, and soapiness; (8) must have the quality of remaining good on the inside until after senescent decomposition is quite apparent on the outside; (9) evenness of maturing and softening over all parts of the fruit; (10) long keeping quality in both common and cold storage; and (11) cut surface should remain bright and attractive for several hours.

Breeding Technique

The flowering habit of the avocado presents two features of importance in developing a suitable breeding technique. Normally the pistils mature before the stamens begin to discharge pollen, which should aid in securing abundant cross-pollination, Only a very small percentage of fruits are set, which presents a serious difficulty in controlled pollination work and has greatly retarded progress.

Flowering Habit

The avocado normally blooms from January to May in the United States, the exact time depending on the locality and the variety. The flowers are perfect, having both pistils and stamens, and pollination is normally accomplished by the agency of insects. The investigation of Nirody (*74*), Stout (*111*, *113*), and Robinson and Savage (*96*) have shown that in the avocado flower the pistil normally matures before the stamens. Nirody's work also established the fact that this alternate development of the sex organs is decidedly synchronous for the tree as a whole, which led him to conclude that cross-pollination is necessary for fruit setting.

The work of Stout in California and Florida, however, shows that the maturing of stamens and pistils at different times (dichogamy) is much more pronounced than was indicated by Nirody. Stout has shown that the flowers of a particular tree normally have two distinct periods of opening instead of one. During the first opening the stigmas of the pistils are receptive but the anthers are not yet mature; and during the second opening of these same flowers the pollen is shed, but the stigmas are no longer receptive. His work led him to group all of the varieties studied into two classes from the standpoint of periods of flower opening, as explained in the next paragraph. He observed, however, that weather conditions markedly affect the periods of flower opening and the degree of overlapping of these periods. Stout's important work was later confirmed by Robinson and Savage (*96*). Skutch (*103*) has reported on avocado trees in Panama that exhibit an erratic behavior with regard to flowering habit.

The normal behavior may be briefly summarized as follows: Under favorable weather conditions the flowers of varieties in group A have a first opening during early forenoon when the pistils are receptive but

no pollen is shed. By midday they begin to close tightly. At about this time, with some overlapping in certain varieties, the flowers that opened and closed in the forenoon of the previous day now have a second or afternoon opening and shed pollen. In group B, the first opening when the pistil is receptive normally takes place in the afternoon while pollen is being shed by the group A varieties on their second opening. The second opening of group B flowers normally takes place the following morning, when they shed pollen, which is ready for transfer to the receptive pistils of group A flowers opening for the first time. Thus the complete flowering cycle of group A varieties includes the forenoon of one day and the afternoon of the next, extending over approximately 30 to 36 hours; while the group B varieties complete their cycle during one afternoon and the next forenoon, in 20 to 24 hours. To insure pollination in the greatest degree, mixed orchard plantings of the two flowering groups should generally be made.

As to the need for varieties of the reciprocal group as pollinizers, an important exception is the Fuerte variety (group B) as grown in the most favorable districts in California. Here the synchronization of the two openings of flowers is not complete because of cooling breezes, and this results in several hours' overlap with consequent opportunity for self-pollination. No interplanting of group A and B varieties is required in such a case (*95*).

All attempts to germinate avocado pollen in culture media have so far been unsuccessful.

Control of Pollination

The avocado produces an enormous number of flowers, of which only a very small percentage even under the most favorable conditions set fruit that is held to maturity. This makes the bagging technique of very little value. This handicap, however, is counterbalanced by the dichogamous nature of the avocado, already explained, which normally leads to a high percentage of cross-fertilization. If the expensive tree-tenting technique is employed (covering trees of two varieties under one tent) with the use of bees to transfer the pollen, abundant results should be achieved. To facilitate this it would be desirable to propagate the two parental varieties on the same stock or to graft one into the other. One variety, Collinson, does not produce pollen, and by using it for the seed parent even the possible error from the overlapping of the first and second flower-opening periods would be obviated. Neither is emasculation necessary with such a flower.

Most of the achievements in avocado breeding so far have resulted from the use of open-pollinated seeds from mixed plantings. Such superior varieties as Fuerte, Taylor, Wagner, Lula, and Collinson give an indication of what may be accomplished. Department workers have recently succeeded in making some artificial cross-pollinations by the use of the bagging technique (Collinson×Fuerte, Taylor×Fuerte), but the seedlings have not yet reached the fruiting stage.

Breeding for Disease Resistance and Other Characteristics

The Department project on avocado breeding, begun in 1932 under the leadership of Traub, Stevens, and Robinson, is concerned primarily with breeding for disease resistance. Avocado varieties show wide

variation in resistance to avocado scab (*Sphaceloma perseae* Jenkins), the major disease of avocado in a humid climate, as well as to other diseases. The work has now been carried on for three seasons. The testing technique consists in exposing the plants to natural infection and to artificial inoculation with pure cultures. Some seedlings produced as a result of cross-pollinations are used in these experiments, but up to the present the larger number have been from open-pollinated seed from mixed plantings of the desired parents. The percentage of seedlings that show resistance to avocado scab varies widely among different varieties, as is shown in table 2.

TABLE 2.—*Percentage of seedling plants showing resistance or susceptibility to avocado scab, Sphaceloma perseae*

Season and seed parent variety	Seedlings tested	Highly resistant	Slightly resistant	Highly susceptible
	Number	*Percent*	*Percent*	*Percent*
Seeds of 1934 season:				
Collins	100	3.0	67.0	30.0
Perfecto	190	2.6	26.8	70.6
Fuerte	128	2.3	21.8	75.9
McDonald	87	0	0	100.0
Wagner	99	1.0	39.3	59.7
Taylor	92	0	57.6	42.4
Lula	84	0	14.2	85.8
Waldin	86	2.3	3.4	94.3
Seeds of 1935 season:				
Taylor	47	14.8	27.2	58.0
Collinson	131	97.1	2.2	.7
Winslowson	30	10.0	0	90.0
Lula	122	40.9	25.4	33.7
Kellerman	29	96.6	3.4	0

With such tests as a basis, appropriate parents are being selected for use in crossing. Collinson and Kellerman seedlings, with a relatively high percentage resistant to scab, deserve special attention from breeders. Duplicate tests of seedlings can be made in two localities at once by using the method of splitting the avocado seed into two or more fractions before planting and thus growing two or more plants from it, as suggested by Traub and Auchter (*125*).

The ecological races of the avocado vary considerably in resistance to low temperature. The lowland or West Indian types are the most frost-tender, Guatemalan more hardy, and Mexican most hardy. Harris and Popenoe (*30*) have shown, by the freezing-point lowering technique, that the tissue fluids of the West Indian type freeze at somewhat higher temperature than those of the other two races. They conclude that since the difference in freezing points of tissue fluids is slight, this character is only one of the causes responsible for the considerable variation in resistance to low temperature.

The varieties secured as a result of open pollination indicate that suitable combinations with respect to resistance to low temperature may be secured even when varieties of the West Indian race are used as one of the parents. Collinson, apparently a West Indian-Guatemalan cross, is almost as hardy in this respect as some of the Guatemalan types. The Booth seedlings, apparently crosses of the same class, also seem to be quite resistant to low temperature. Gottfried, apparently a Mexican-West Indian cross, is very hardy. Crosses between the Guatemalan and Mexican races are quite frost-resistant,

as would be expected. Good examples of this are found in Fuerte and Lula.

Differences in reaction to storage conditions may determine to a considerable degree the value of avocado varieties as breeding material or for fruit utilization. With the Winslowson variety in Florida, losses have resulted from marked discoloration of the pulp, especially under low-temperature conditions of shipment or storage. A storage temperature of 50° F. completely inhibits ripening in the Winslowson avocado but is not detrimental to the Collinson and some other varieties.

Breeding for certain other desirable characters, such as tree habit, stem length and strength, skin thickness and color, seed size, quality and color of flesh, and oil content, should also be seriously considered.

A recent study by Traub and Robinson [5] of 18 open-pollinated seedlings of Lula in the grove of Ivey Futch at Lake Placid, Fla., has shown a very wide variation in oil content (5 to 22.25 percent) as well as in fruit size, percentage of flesh, and skin thickness. Small-sized fruits largely predominate, for only 5 out of 33 produce fruit approximately as large as that of the parent variety (over 10 ounces). The percentage of flesh also varies widely in the series, although the greater number tested gave about 50 percent of flesh compared to the whole weight of the fruit. The skin was generally thin in all specimens. Only one seedling somewhat resistant to scab was found in the whole series. Tree habit varies from low and spreading in a few instances to the upright columnar growth characteristic of the Lula, the latter habit predominating.

Cytology of the Avocado

The cytology of the avocado has received very little attention. Van Elden at the California Agricultural Experiment Station (*10*) has determined the diploid chromosome number in several of the species of *Persea* to be in all probability 24. In 1932 Longley (see appendix) determined 12 as the haploid chromosome number in the varieties Lyon, Linda, Taft, Queen, Panchoy, Taylor, Wagner, Puebla, Fuerte, Winslowson, and a West Indian seedling.

DATE

The earliest known records of Egypt and Assyria show that the date palm (*Phoenix dactylifera* L.) held a very important place among the food crops grown in those countries. It has been cultivated from time immemorial in the Tigris and Euphrates Valleys and in Arabia as a major food crop. The traditional food of wandering nomads consisted of dates and camel's milk. Date culture spread to north Africa and Spain and Mexico and more recently to the United States (in California, Arizona, and Texas) and other countries where conditions are favorable. Attempts are now being made to introduce date culture into Queensland, Australia.

Date Introductions and Varieties in the United States

Investigations by W. T. Swingle of the conditions in the Old World under which date culture had long been successful, published in 1901 and 1904 (*114*, *115*), showed that arid regions of intensive summer

[5] Unpublished work.

heat practically free from summer rains or high humidity must be chosen to establish this new crop successfully in the United States. At the same time abundant water must be available for irrigation. The irrigated valleys of the Southwest appeared to fulfill these requirements, although it was early recognized that different sets of varieties might be required to suit the peculiar local conditions of temperature, soil, and humidity. Though the date palm requires intense summer heat, it is not truly tropical but subtropical, withstanding rather severe winter frosts. It is adapted to a wide range of soil conditions and is especially tolerant of alkali in amounts likely to be injurious to many other fruit crops. The Coachella Valley in southern California has proved nearly ideal for the late-maturing varieties, which require a high cumulative total of heat units for fruiting, and for the Saharan varieties in general.

In Arizona the conditions are different, particularly in the Salt River Valley, where rainfall occasionally occurs in midsummer, at a time when this is fatal to the most exacting of the north African varieties because it causes fruit spoilage. For this section the most promising varieties are those not too late in maturing and somewhat resistant to summer humidity. This eliminates most of the north African dates and leaves Egyptian and Persian Gulf varieties as the most desirable. The Imperial Valley in its climatic complex is approximately intermediate between these two sets of conditions, but date culture has not been extensively undertaken there. In Texas the Winter Garden and Laredo districts, in the southwestern part of the State, are apparently suitable for date culture. In the lower Rio Grande Valley tests of numerous varieties are under way to discover, if possible, "rain resistant" varieties that may be successfully grown in this fertile section.

The importation of date seeds and plants through the Patent Office of the United States Government is mentioned as early as 1860, when a collection was received from Palestine (*129, p. 34*).

For many years prior to the importation of offshoots of named varieties, seedling dates had been grown in California (*54*), Arizona, southern Texas, and southeastern United States. The first successful introduction of offshoots of named varieties was made by the Division of Pomology of the Department in 1889, as recorded in the Yearbook of the Department for 1890 and reported in more detail by Toumey (*123*), of the Arizona Agricultural Experiment Station. This importation consisted of 59 offshoots from Egypt, 9 from Algeria, and 6 from Maskat. Arrangements for these shipments were made through the United States consuls in the various regions.

According to Toumey, only those offshoots planted at the old Arizona Experiment Station near Phoenix gave encouraging results in growth and prompt fruiting, nine of the ten planted surviving. Thirteen of the introduced palms set out at Yuma were swept away in the Colorado River flood of 1891. Ten plants sent to New Mexico died after a few years. Of the 39 offshoots divided among four stations in California (Pomona, Tulare, National City, and Indio), 22 were reported by Toumey as alive in 1898, but none had matured fruit up to that time. Of the four palms sent to Indio, two of the Rhars variety became established and are recognized

as the oldest date palms of a standard variety growing today in California.

In the Phoenix, Ariz., planting, only four of the nine proved to be females. Although the varieties included in this shipment proved in many cases to be wrongly labeled and contained a large proportion of males, the good growth and prompt fruiting at Phoenix encouraged the importation of offshoots on a larger scale.

Accordingly in 1899 and 1900, by cooperative arrangement with the Arizona Agricultural Experiment Station, importations were made by W. T. Swingle, of the Department. These consisted of 447 offshoots comprising 27 varieties secured from the best date-growing oases of Algeria, and included the Deglet Noor variety (*114*). Most of the importation (391 offshoots) were planted at the Cooperative Date Garden, Tempe, Ariz.; 21 were planted at the Phoenix station; and 35 were divided between the Pomona and Tulare substations in California. The possibilities of the great valleys of the Salton Basin in California for date growing had not at that period been recognized. Such large shipments were made feasible by the discovery, through trial shipments made by Swingle, that offshoots as cut from the date palm could be packed in ventilated crates with any suitable fiber, such as straw or palm fiber, and survive a 2 or 3 months' journey. Previous shipment had consisted of bulky tubs in which offshoots had first been rooted before shipment, requiring a year's preparation and entailing much expense. Of the offshoots of this importation planted at Tempe without previous rooting, more than 75 percent survived and made satisfactory growth, a better showing than was made by the tubbed palms, of which about 58 percent lived.

The success of the importation of freshly cut offshoots led to further large-scale shipments both by the Department and by private persons. The records indicate that in some of these early importations between 1901 and 1910 the Department acted merely as agent for private importers. Among these private importations may be mentioned those of Bernard G. Johnson in 1903, and again some years later, acting for the Date Growers Association, and also those of E. F. Churnard, acting for the Imperial Date Co., about 1905.

Importations by the Department were made in 1901–2 from Egypt and the Persian Gulf region under the leadership of David Fairchild, and again in 1905 from Algeria and Tunis by Swingle. The latter importation was divided between the cooperative date stations at Tempe, Ariz., and Mecca, Calif. The Mecca station was established in 1904. Three years later (1907), because of the threatened flooding of the Mecca station from the break in the Colorado River, the United States Experiment Date Garden at Indio, Calif., was established. At these various stations, as well as by private growers, upward of 140 identified date varieties have been tested out since 1890.

Among the largest importations of date offshoots should be mentioned the two Department importations from Egypt and the Sudan under the direction of Mason (*63*, *64*), the first in 1913–14 and the second in 1922. On the last trip alone 9,000 offshoots, largely of the Saidy variety from Egypt, were obtained by Mason. In 1927 a small introduction (11 offshoots) of the Medjool date was made by W. T. Swingle from Morocco. This variety is famous in commerce as the

Tafilet date and had not been introduced into the United States previously. Again in 1929 R. W. Nixon visited Iraq and the Persian Gulf region for the Department in quest of varieties more or less resistant to rain and humidity, especially needed for trial in the Rio Grande Valley and other locations subject to occasional humid conditions. This importation included 28 varieties, a total of 1,375 offshoots.

The Department introductions since 1889 have totaled 1,076 lots (upward of 20,000 offshoots). Many varieties proved to be inferior and of questionable varietal status, but the more important varieties have been preserved in various collections of the Department and of the State experiment stations in California, Arizona, and Texas. The chief varieties now grown commercially in California and Arizona are indicated in table 3.

TABLE 3.—*Imported varieties of dates grown in the United States*

Name	Chief varietal characters	Source	Date first introduced	Location	Approximate acreage (estimated)
					Acres
Barhee	Soft; amber; late-ripening; edible in "khalal" stage; heavy producer.	Iraq	1913	Coachella Valley, Calif.	2
Dayri	Semidry; dull reddish-brown to almost black; withstands humidity with less damage than most varieties.	do	1913	Coachella Valley and Bard, Calif.; Salt River Valley, Ariz.	5
Deglet Noor	Semidry; amber; delicate and distinctive flavor; very susceptible to injury from rain and high humidity.	Algeria, Tunisia.	1900	Coachella Valley, Calif.	2,400
Halawy	Soft; amber; early-ripening; not seriously damaged by occasional rains and high humidity.	Iraq	1902	Coachella Valley and Bard, Calif.; Salt River Valley, Ariz.	30
Hayany	Soft; very large; black; early-ripening; good fresh date but does not cure well; preferred by some because less sweet than other commercial varieties.	Egypt	1901	Salt River Valley, Ariz.	20
Iteema	Soft; amber; sours and ferments more easily during high humidity than any other commercial variety.	Algeria, Tunisia.	1900	do	20
Khadrawy	Soft; amber; early-ripening; smaller palm than any other commercial variety.	Iraq	1902	Coachella Valley and Bard, Calif.; Yuma and Salt River Valley, Ariz.	65
Khalasa	Soft; amber; rich, delicate flavor.	Hasa, Arabia	1913	Coachella Valley, Calif.	4
Khustawy	Soft; amber; small with skin inclined to be puffy; not seriously damaged by occasional rains and high humidity.	Iraq	1902	do	20
Maktoom	Soft; amber; not seriously damaged by occasional rains and high humidity.	do	1902	Coachella Valley; Calif.; Salt River Valley, Ariz.	10
Rhars	Soft; amber; early-ripening; considerably damaged by occasional rains.	Algeria, Tunisia.	1900	do	5
Saidy	Soft; almost semidry; dull-brown; flavor said to improve with storage.	Egypt	1901	Coachella and Imperial Valleys, Calif.	80
Sayer	Soft; reddish-brown; not seriously damaged by occasional rains; said to be drought-resistant in Old World.	Iraq	1902	Coachella Valley, Calif.; Salt River Valley, Ariz.	3

TABLE 3.—*Imported varieties of dates grown in the United States*—Continued

Name	Chief varietal characters	Source	Date first introduced	Location	Approximate acreage (estimated)
					Acres
Tazizoot	Soft; amber; considerably damaged by occasional rains and high humidity.	Algeria	1904	Coachella Valley, Calif.	2
Thoory	Dry; best of the bread dates introduced; dull-yellow or straw color.	do	1912	Coachella and Imperial Valleys, Calif.	4
Zehedy	Semidry; amber or straw color; obovate.	Iraq	1902	Coachella Valley and Bard, Calif.; Salt River Valley, Ariz.	40

Albert and Hilgeman (*2*), in 1935, reported the varieties most commonly grown in Arizona (in order of importance) as Khadrawy, Zehedy, Iteema, Khustawy, Hayany, Deglet Noor, Halawy, Maktoom, Khalasa, Sphinx, and Sayer. Although commercial date growing in Arizona began with the planting of imported offshoots by Bernard G. Johnson near Yuma in 1912, the real development of commercial date culture did not begin until about 1920, when offshoots became available in increasing quantities. A comparison with the varieties listed by Metzler (*68*) in 1925 shows the increasing popularity of Zahidi and the addition of Khalasa and Sayer to the list of promising varieties for Arizona. Between 1925 and 1935 the number of palms in commercial plantings increased from 7,000 to 24,000.

According to Paul (*82*), the largest private importations were those of Bernard Johnson and his associates (1912–15), amounting to about 16,000 offshoots, chiefly varieties from north Africa, and the extensive collection of varieties made by F. O. Popenoe and his associates, first in 1912 of 1,000 Deglet Noor offshoots from Algeria, and again in 1913, of about 5,000 offshoots from Algeria and 7,000 from Persia, representing about 106 varieties. At the same time (1913) the American Date Co. imported 1,700 offshoots. After 1915 the exportation of date offshoots from the French colonies was prohibited.

BREEDING METHODS

The varieties of the date grown commercially today undoubtedly originated through the centuries from selection of chance seedlings. The slow progress in date breeding in recent times can be better understood by a consideration of the nature of the plant. The date palm is a monocotyledonous plant. In this plant group, increase in diameter of trunk is accomplished by the growth of the vascular bundles scattered usually throughout the entire stem and not in an outer ring, as in the dicotyledons, in which the meristematic or growing tissue is quite abundant and easily gives rise to new buds. In the case of the date species *Phoenix dactylifera*, a comparatively few offshoots (which are true to the parental type) are produced in the lifetime of the plant. This condition, coupled with the length of time required to bring date seedlings into bearing—5 years or more—

and the demonstrated rarity of choice-fruited seedlings, makes it very difficult to carry on effective breeding work.

In the early days of the date industry in this country many date seeds were distributed by the Department for planting in California, Arizona, and southern Texas, but the results of these plantings have generally been disappointing. The date seeds distributed for testing were the result of pollination by a male of the same type in practically all cases and were classed as "pedigreed seeds" as distinguished from seed of open-pollinated dates. Because of close planting or neglect most of them have not been effectively tried out. In Arizona and southern Texas it might be profitable to undertake a study of these and other seedling dates and propagate the more promising ones as a basis for breeding new varieties better adapted to the local climatic conditions. Any outstanding males could be preserved for breeding and further propagation at the same time.

The following California date growers have produced seedling palms that are being propagated as new varieties and may have merit: B. H. Hayes, Indio; Mrs. Nolan, Indio; C. E. Cast, Mecca; Mr. Wise, Mecca; Francis Heiny, Brawley; and J. E. Miller, Bard.

In 1916 the Arizona Agricultural Experiment Station initiated a date-breeding project that is now in its twentieth year. The method employed is that of inbreeding within sib-pollinated lines. Originally the Deglet Noor was pollinated with a male seedling of the same variety, and selections have been made in three generations secured by sib pollination. The fourth-generation seedlings are being set in the field in 1937. The work is being carried on by W. E. Bryan, plant breeder at the Arizona station.

A bud variation in the Deglet Noor date was reported by Shamel (*106*). It consisted in variation in breadth of leaf pinnae and in greater thickness and length of the fruit, but the quality and seed characters were of the original type. Mason (*65*) reported a sectorial mutation in the Deglet Noor involving only one portion of the palm. Bud mutations, however, appear thus far to be a comparative rarity in *Phoenix* and seem unlikely to afford a basis for the selection of new or superior varieties or strains.

Among the varieties propagated on a commercial scale, the question of "strains" would seem to warrant some investigation. Whether minor variations reported from time to time are due to their being derived from "satellite seedlings" (seedlings differing only slightly from the parent variety), as described by Mason, or are due to differences in soil and other factors, can probably be determined only by growing the material in question under uniform conditions. In some instances it has been found that what appeared to be strain differences were in fact errors in nomenclature, the differing strains being in fact distinct varieties. The reverse situation has also been encountered, two or more names being given to plants of the same variety.

Factors Affecting Technique of Breeding

Although little actual breeding work has been carried out with dates, the flowering habit, pollen viability, pistil receptivity, and the technique of controlling pollination have received attention.

Flowering Habit

In flowering habit the date palm is normally dioecious, different plants bearing the staminate and the pistillate flowers. Some intermediates, known as fruiting males, have been discovered, with a whole series of intermediate and hermaphrodite flowers on their inflorescences. According to Leake (*59*), it is probable that the few fruits reaching maturity on these abnormal plants are derived from those female flowers in which stamens have completely aborted. While hand pollination is universal in commercial practice, under conditions of nature pollen is primarily wind-carried, although insects and birds may also be instrumental. The date inflorescence, according to Nixon (*77*)—

is a branched spadix with sessile flowers rather closely grouped along the distal portion of 25 to 100 or more spikes, 6 to 36 inches in length. A single very large inflorescence may carry up to 8,000–10,000 flowers, and more than 5,000 dates have been counted on one very large unthinned bunch. This makes it possible to get a very large number of dates from a single pollination.

In experiments involving controlled pollination care must be taken to prevent intermixture with wind-blown pollen.

Bois (*6, 7*) made a report on a monoecious date tree and also on a male fruiting date and on date fruits without seeds. Swingle (*118*) reported on vegetative and fruiting branches in the date palm and sterile intermediates between them.

Pollen Viability and Pistil Receptivity

Prior to the work of Stout (*112*), who carried out germination experiments in culture media, it was generally supposed that date pollen 1 or more years of age, stored under ordinary conditions, could be effectively used. Stout's work has shown that such pollen does not germinate on culture media and is apparently worthless in attempts to effect fertilization and setting of fruit. The experiments of Albert (*1*) show that pollen stored from May 13 to the following March 4 gave very little germination (1 to 5 percent) at the end of the period when stored in either a sealed or an open vial at room temperature. A fairly high percentage of germination was maintained for several months, however. Pollen put in cold storage for the same period (May 13 to Mar. 4) gave excellent results when stored in a sealed vial—87 percent of germination at the end of the experiment—but only 3 percent when stored in an open vial. At the end of 7 months 19 percent of the pollen cold-stored in closed vials was still viable. These experiments indicate that date pollen under proper cold-storage conditions retains its viability for a considerable period, which makes it possible, as Albert points out, to store pollen from one fruiting season to another.

Leding (*60*) reported results indicating that the pistils of the flowers remain receptive to a marked degree for 10 days or more and to a much less extent for more than 30 days. Albert (*1*) has obtained somewhat different results. His work shows that the stigma of the date remains receptive over a period of 15 to 18 days.

Control of Pollination

Nixon (*75, 76*) has devised an effective method of artificially controlling pollination in the date. He points out that it is difficult to bag an entire cluster of female flowers satisfactorily, since the basal flowers on the central strands are usually still far down within the

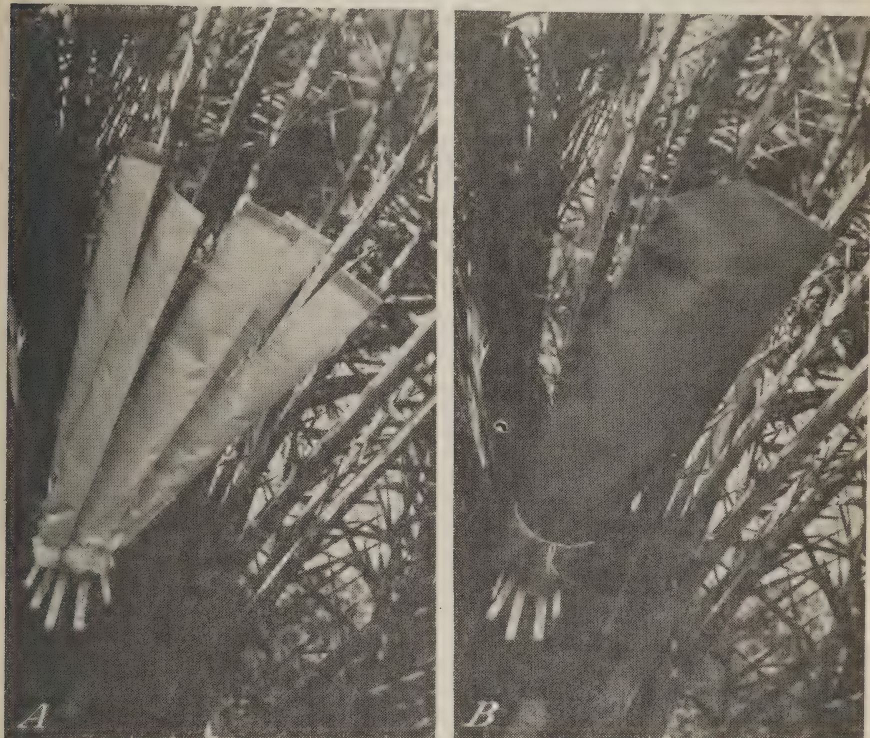

Figure 9.—Method of controlling pollination in the date, showing types of bags used in applying different pollens on the same inflorescence. In *A*, each bag encloses a set of strands. Emerging from the bags at the base are the copper wires used to release pollen sealed in small packets at the upper end within. *B* shows a larger bag placed over the others for additional protection.

axil of the leaf when the spathe first begins to open. To cover the strands for protection before pollination, long, narrow bags were made of heavy brown wrapping paper in two thicknesses, sealed separately—essentially two bags, one within the other—and the whole spathe was then covered with a larger bag (fig. 9). Nixon describes the method as follows:

In 1926 a method was worked out for applying several pollens to different strands on the same inflorescence which greatly facilitates field work and insures a minimum of contamination. This consists in sealing the pollens in small paper packets, about 2½ by 5 inches, and gluing these small packets within the larger bags, about 3 by 24 inches, at the upper or sealed end. After the large bag has been placed over the strands to be pollinated and the lower or open end plugged with cotton and tied, the pollen is released by pulling a copper wire attached to a small tuft of cotton inside the sealed packet that contains the pollen. This breaks

the pollen packet and releases pollen so it falls on the female flowers. This is not done until all of the bags are in position and is accomplished by holding the upper end of the bag with one hand and pulling the lower end of the copper wire with the other. The small packets used were made of heavy glassine paper, two thicknesses, each sealed separately, and before being placed within the pollination bags they were washed in a strong solution of bichloride of mercury. The 3 by 24 inch bags were similarly made of two thickness of glassine paper, each sealed separately, and it was possible to observe the action of the wire plunger in effecting pollination.

This method eliminates the necessity for direct contact with pollen in the field, and the pistillate flowers are exposed only during the moments while the bags are being placed in position. As was done in these experiments, it is advisable to protect all the bags on a single inflorescence with a larger bag or hood.

Xenia and Metaxenia [6]

One of the usual operations carried out in date culture is that of artificial pollination. This is an ancient practice, necessary because of the dioecious nature of *Phoenix dactylifera* and the uncertainty under commercial culture of depending on the natural method of wind pollination. Once or twice a week for a period of several weeks spikes of the male flowers are tied in the female inflorescences as they open, to secure a full set of fruit. That the pollen of certain males had an effect on the fruit was probably noticed in a vague way in the countries where dates have been grown for many years, although there is no record of such observations. The growers recognized that their main varieties gave best results when pollinated by certain males, as pointed out by Schweinfurth (*102*). Observations of similar effects in the apple date back some 200 years, as is shown in the report of Turner (*128*). Degman and Auchter (*24*) have recently given a critical review of some of the literature on this subject for the period 1876 to 1934.

In 1901 Schweinfurth (*102*) pointed out that the indiscriminate use of pollen of seedling males is known to cause changes in the shape of the resulting seed, a character that supposedly remains fairly constant for the variety when a single male is used. It might be inferred from the text that there might be other variations, and this probably led Popenoe (*86*) to make the statement that Schweinfurth reported "the characteristics of the male had an influence on the fruit which resulted." Vinson (*130, p. 426*) in 1911, in commenting on the differences in fruit maturity between certain date palms at the Tempe Date Garden in Arizona, suggested the possibility of an influence of pollen on the maturation of the pericarp. Drummond (*25*), superintendent of the United States Experiment Date Garden at Indio, Calif., from 1908 to 1924, noticed, as recorded by Popenoe (*86*), that the pollen of *Phoenix canariensis* Hort. influenced the quality of the fruit of the Rhars variety, producing a better date than was obtained on this variety with pollen of *P. dactylifera*, and in addition that where several varieties of males were tried on different palms, markedly different results were observed—"a difference of as much as one third in size, and of 20 days in the time of ripening, seem to have been due to a change in the male used for pollinating."

Similar observations were made by Swingle between 1922 and 1925 and by L. M. Huey, of Bard, Calif., in 1924 (*120*). These observations

[6] Xenia is the manifestation in the seed endosperm of characters inherited from the pollen plant through union of nuclei, analogous to the fusion of egg and sperm nuclei to produce the embryo. Metaxenia, or ectogeny, refers to the influence of the male germ cell after fertilization on the ovary and adjacent parts.

led to controlled experiments by Nixon, and in 1926 (*75*) he reported experiments begun in February 1925 at the United States Experiment Date Garden, Indio, in which he used pollens that seemed most likely to have different influences on the resulting fruit. In the case of two pollens used in eight trials he found that there was a significant difference in the size of the seed produced, and in seven out of eight trials there was a significant difference in the size of the fruit, with a difference in the eighth still tending in the same direction. There was also a marked difference in the time of ripening in the Fard pollinations. Swingle (*119*) in 1926 also reported on the influence of pollen on the seed and fruit of the date. Nixon continued his studies (*76*, *77*) and later (*78*) extended his work to include a study of similar effects in relation to pollination between different species of *Phoenix*. Crawford (*23*) has shown that the influence of pollens on the Deglet Noor date is effective early in the development of the fruit and seed (May to July), with greatly diminished differential effect as the fruits approach full development.

Although the experiments of Kraus with apples, reported in 1921 (*55*), did not substantiate the conclusions of other workers who reported skin-color changes in the apple due to the use of pollens of other varieties, he pointed out that any such effect would have to be through a stimulating agent transmitted from the seed (embryo) to the somatic tissue. Swingle in 1926 (*119*, *120*) suggested that the embryo and endosperm may secrete one or more substances (hormones) that influence the development of the ovary (mother plant tissue). He proposed the term "metaxenia" for this effect of pollen upon the maternal somatic tissue. Schaffner (*104*) points out, however, that xenia describes an effect of genetic factor balance and that the phenomenon for which metaxenia was proposed is physiologic. He therefore offers the term "ectogeny" in place of metaxenia.

The practical benefits from this discovery are readily apparent, since it gives the date grower a greater command over his material at no added expense, making it possible, within limits, to regulate the size and time of maturity of his date crop. Indirectly the quality may also be affected, since dates ripening during unfavorable weather are generally inferior. Since 1931 commercial application has been made of this finding, and male date palms known to give desirable differential effects are highly valued. Propagation of offshoots from such males makes possible the wider use of this practice.

Cytology of the Date

As a consequence of the difficulties involved in breeding, there is not even a rudimentary knowledge of the genetics of dates. Nemec (see table 5 in the appendix) reported the diploid chromosome number in *Phoenix dactylifera* as 28, and Narayana (*73*) determined the haploid chromosome number of *P. farinifera* Roxb. to be 18.

PINEAPPLE

The pineapple (*Ananas sativus* Schult. fil.), belonging to the Bromeliaceae or pineapple family, is native to South America and was brought to Europe by the Spanish explorers. Early in the seventeenth century its cultivation in England and continental Europe in

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glass houses was undertaken. Amateur European gardeners raised many seedlings after 1765, most of which have not been continued to the present. The pineapple is now grown primarily in the open in regions to which it is adapted. The first extensive shipments of fresh pineapples were apparently made from the Canary Islands. In most tropical countries the pineapple was grown for many years only for local consumption.

The pineapple was commercially introduced into Florida at Key West from Cuba about 1860, and in the next 10 years pineapple growing was attempted on the adjacent keys. Still earlier introductions, notably that of Henry Perrine (*83*) about 1837, had failed to start a commercial industry. Large-scale pineapple production for shipment to the northern markets in the fresh condition had its origin with the late T. E. Richards, of Eden, who made his first successful shipment of fruit in 1864 (*43*). The industry spread also to central Florida in Lake, Orange, Volusia, and other interior counties, but never reached large proportions, and gradually declined in this section of the State. By 1890 it had become centralized almost exclusively in the east coast pineapple region, extending from the vicinity of Fort Pierce southward to Miami (*131*). In the early twentieth century, according to Hume and Miller (*45*), 95 percent of the pineapples grown in Florida were Red Spanish and 99 percent of all plantings consisted of Red Spanish, Smooth Cayenne, Abachi, Porto Rico, and Golden. At that time for extensive open field culture the Red Spanish was the only variety recommended. For growing under lath sheds Cayenne, Abachi, and Golden were given the preference, and of these Cayenne was evidently the best.

The industry reached a peak prior to 1917, when cultural difficulties began to result in decreased yields. With the freeze of 1917, many of the plantations were permanently abandoned or neglected. With the decline of pineapple culture in Florida the production in Cuba and Puerto Rico increased to supply the demand for fresh fruit in continental North America. Since 1933 the industry is being revived in Palm Beach County on flatwoods soil under irrigation culture. The Abachi (fig. 10, *B*) is preferred, although the Red Spanish is also planted.

In Asia the culture of the pineapple for canning is carried on in the Singapore area, where the industry developed prior to 1895. Pineapple culture is a thriving industry in Queensland, Australia, where it was first introduced in 1854. Some of the fruit is canned. There are other minor production areas in other parts of the world, including Taiwan, Madagascar, Ceylon, Borneo, Siam, Ecuador, and Martinique. Pineapple culture in South Africa began after 1865, and extensive areas are devoted to it near Bathhurst and in Natal and northern and northeastern Transvaal. Most of the fruit is exported, but some canning is carried on.

The pineapple, according to Johnson (*50*), was introduced into Hawaii about the beginning of the nineteenth century. In 1885 John Kidwell began growing pineapples in Manoa Valley in Honolulu. Out of a number of imported varieties Smooth Cayenne was selected as the best, and about 1890 Kidwell was growing this variety near Pearl Harbor. Pineapple canning was begun in a small way in 1892.

Following the homestead settlements in 1901, the pineapple industry expanded rapidly. From a few thousand cases of canned pineapples in 1903 it grew to 2,600,000 cases in 1913. In recent years the production has reached 12,000,000 cases yearly.

In Hawaii, according to Higgins (*35*), in 1910 the Smooth Cayenne was the only variety grown commercially, but it was realized that

Figure 10.—*A*, **Fruiting plant of Smooth Cayenne pineapple, grown in Hawaii. It is the variety grown commercially in Hawaii and the foremost pineapple variety in the world.** *B*, **Fruiting plant of Abachi pineapple, grown in Palm Beach County, Fla.; one of the varieties grown in Florida.**

there were several strains of this variety. One of these—the Hilo or ordinary strain—is characterized by a smooth, robust plant with fruit produced on a very short stem, which usually carries no slips or very few. Another strain, introduced from Queensland, has barrel-shaped fruit. The Red Spanish was tried on a commercial scale but did not meet with favor.

In Hawaii today the Smooth Cayenne (fig. 10, *A*) is grown almost exclusively. The strain grown appears to be mainly the introduction from Queensland. The Smooth Cayenne is the leading pineapple variety in the world, for it is produced on a large scale in Hawaii, Queensland, and elsewhere. Its exact origin is not definitely known, and the first reference to it in the literature appears in the 1840's, when it was introduced from France into England for greenhouse culture. The leaves of the plant have straight margins. The fruit is large, ranging from 4 to 8 pounds, oblong in form, and yellow in color. The core is small, the flesh very juicy, and the flavor rich and sweet.

The Red Spanish is probably the second in general importance. It is the chief variety grown in Florida (until recently), Cuba, and Puerto Rico. It is characterized by its relatively vigorous and hardy

constitution and medium size of fruit, which ranges from 2 to 5 pounds in weight. Much of its popularity is due to its ability to stand rough handling and long shipment. The usual shape is oblong, and the color varies from yellow to reddish. The core averages three-fourths of an inch in diameter, and the flesh, which is juicy and white, has a pleasant subacid flavor due to the blending of sugars and acids.

The Queen, which is preferred in South Africa and is one of the three leading varieties in Australia, is the third leading pineapple variety. There are a number of subvarieties of the Queen.

Classification of the Pineapple

A key for the identification of pineapple species and varieties was published in 1919 by Bertoni (*4*) in his monograph on the genus *Ananas*. This includes six species, *A. guaraniticus* Bertoni, *A. microstachys* Lindman, *A. microcephalus* Bertoni, *A. muricatus* Schult. fil., *A. bracteatus* Schult. fil., and *A. sativus* Schult. fil., and also the botanical varieties of the last two species.

The cultivated pineapple varieties have been classified by Munro (*72*) and Hume and Miller (*45*). Some of the distinctions used by Munro are of doubtful horticultural value, and the classification of Hume and Miller, which places them in three large horticultural groups having a general resemblance, is probably more useful:

A. Queen group.—The typical variety of this group is the Golden pineapple. The fruit is characterized by yellow flesh, pointed eyes sloping upward from the sides, deep yellow color, syrupy juice; flavor rich and sweet. Plants usually are not adapted to open field culture. Under this group are classed Black Ripley, Egyptian, Golden, Green Ripley, Pernambuco, and Abachi.

AA. Cayenne group.—The Cayenne, commonly known throughout Florida as Smooth Cayenne, may be regarded as the type of this group. The flesh is light yellow, the eyes broad and flat, not elevated at the nipple; the leaves are smooth or serrated; the plants are strong, upright, vigorous growers. Under this group are included Smooth Cayenne, Enville, and Rothschild.

AAA. Spanish group.—The typical variety of this group is the Red Spanish pineapple. The flesh is white; the eyes are flat but elevated at the corners of the bracts; the leaves are strong, stiff, and serrated. Under this group are classed Blood, Porto Rico, Prince Elbert, Red Ceylon, Sugar Loaf, Red Spanish, and Yellow Ceylon.

Johnson (*50*) published an extensive reference list of pineapple varieties, and he refers to an unpublished bibliography of varieties compiled by Wendt in 1925.

Breeding Technique

The technique of controlling pollination in the pineapple does not present any difficulties. The cultivated varieties used are as a rule highly self-sterile, so that emasculation is not necessary. Open pollination is also a minor factor, for seeds are rarely found even in mixed plantings. The pollen is usually transferred to the stigma from fresh anthers of the pollen parent. No work apparently has been recorded on pollen germination, storage, rate of pollen-tube growth, and duration of pistil receptivity in the pineapple. Traub and Robinson [7] have used over a period of several days pollen from pineapple inflorescences cut off and set in water. Such a procedure is especially valuable when pollen must be transported.

[7] Unpublished work.

The method of chemical treatment of the plants to induce prompt flowering promises to provide a valuable aid to the breeder. The use of smoke as a means of bringing a group of pineapple plants under greenhouse culture into bloom at the same time was accidentally discovered in the Azores many years ago and is there adopted as a common practice today. Rodriquez (*97*) made use of this practice in the field in Puerto Rico, and also treated slips and suckers with ethylene prior to planting. In the latter case the treated plants flowered 6 months before untreated plants of the same lots, but the fruits were small. He also suggests that ethylene might be used on plants in the field in place of smoke. For breeding work the treatment of plants with ethylene and other chemicals that give similar effects in forcing flowering is of distinct value, not only because plants flower earlier but mainly to bring into flower at the same time particular parent plants to be used in crossing. It is also practicable to use solutions of these chemicals, which can be applied to crowns of the plant as well as to the soil around the plant.

Pineapple Breeding in the United States, the Philippines, and Hawaii

The cultivated pineapple shows a remarkable variation in its seedlings and in the many varieties that were introduced by European hothouse gardeners from 1765 onward, but apparently practically none of these are now in cultivation.

Webber, of the Department (about 1900), developed a number of pineapple varieties by hybridization at Miami, Fla. Some of these hybrid seedlings were of high quality, but they have unfortunately been lost.

The Department has introduced a collection of over 50 varieties of pineapples. These are being used in pineapple-breeding work under the leadership of Traub and Robinson. The most promising crosses being made are those between Natal, a variety resembling Queen, which produces large suckers and few slips, but is of rapid growth and fruits earlier than Red Spanish or Abachi, and Red Spanish. None of the seedlings has yet fruited. One of a number of chance Red Spanish seedlings, that by its smooth leaves and other characters indicates hybrid influence, appears very promising. Because of its outstanding shipping quality and hardiness the Red Spanish should be excellent breeding material, since these attributes are generally lacking in the better dessert varieties.

J. M. Capinpin, College of Agriculture, University of the Philippines, Laguna, P. I., reports that genetic studies of the pineapple have been carried on since 1922 and breeding work through hybridization and through selection of mutant strains is still in progress. Selections for disease resistance and fruit quality have been made, and improved strains have been propagated for distribution of the following varieties: Red Spanish, Mindoro, Queen, Buitenzorg, Smooth Cayenne, Variegata, and C–L–c–4. A study of polyploidy (extra chromosomes in the cells) in relation to sterility and seediness in the pineapple is in progress; it has been noted that triploidy (three sets of chromosomes instead of two in the body cells) occurs in some varieties and in seminal progeny of varietal crosses.

The most extensive pineapple-breeding work at the present time is being carried on in Hawaii. As early as 1913 Higgins grew pineapple seedlings at the Hawaii Agricultural Experiment Station, but this work was discontinued. Work started by Lyon and Doty in 1915 at the experiment station of the Pineapple Producers Cooperative Association, as reported by Wendt (*133*), consisted of growing a large number of seedlings from chance seed occurring in Smooth Cayenne fruit. This method has been abandoned. It is remarkable that one chance seedling of the Smooth Cayenne shows a considerable number of Queen characteristics. Wendt points out with reference to the breeding work of Kerns and Doty (1916) that chance Smooth Cayenne seedlings have given inferior results, apparently because of inbreeding. He points out further that vigorous seedlings were obtained by these workers in 1920 from crosses between Queen and Smooth Cayenne. This is also true with reference to other crosses made during the last few years. A number of pineapple varieties were later introduced in Hawaii and hybridization of them was attempted. Krauss (*56*) showed that the development of plants from seeds could be hastened by the use of artificial heat in the germination of the seed.

The hybridization work at the Hawaiian Pineapple Producers Cooperative Association was continued by Collins and Krauss, who are securing very encouraging results. The most promising seedlings are the triploid plants. Johnson (*50*) summarizes this work. In general, he says:

> Crosses between Cayenne and Smooth Guatemala appear the most promising, and very good varieties are being developed with large fruit of good quality. Pernambuco crossed with Cayenne gives fairly good plants with Cayenne characteristics. The purplish green color of the unripe fruit and small eye of the Pernambuco are apparent, though the eyes are more numerous and the fruit larger than Pernambuco. The fruit quality is fairly good, though usually the acid is low.

With reference to ideals in pineapple breeding, Wendt (*133*) lists the following: (1) Vigor of plant; (2) ratooning ability, should produce two to four ratoons, mature rapidly, and fruit at regular ratoon fruiting time (this is not the case with Smooth Cayenne, which produces ground suckers that are slow to mature); (3) fruit characters—Smooth Cayenne type, long, flat-eyed, with square-shouldered top and a smooth but firm and tender flesh of solid texture with high sugar content and of sufficient acidity to be palatable.

Concerning the possibilities for inbreeding and crossing he makes the following points: (1) That individual inbreeding is not practical, since most of the good varieties are self-sterile, as is Smooth Cayenne; (2) that seedlings of the same parentage may be crossed; (3) that seedlings of different parentage may be crossed; (4) that backcrosses may be made on Smooth Cayenne; and (5) that Smooth Cayenne may be crossed with other varieties.

Hagan and Collins (*29*) have studied varietal resistance to nematode injury in the pineapple, including a hybrid between the susceptible Smooth Cayenne and a wild resistant type, Wild Brazil. Resistance appears to be transmitted to the hybrid to a considerable degree. Nematode injury has been considered by many as a potent cause contributing to the decline of the pineapple industry on the

sand dune areas of eastern Florida. The possibility of breeding for resistance to this type of injury opens up a promising field.

Von Kesseler (*52*) has studied varietal resistance of the pineapple to the root rot fungus, *Nematosporangium rhizophoron* Sideris, including 12 varieties and 1 first-generation hybrid population. The hybrid between Wild Brazil and Smooth Cayenne showed inheritance of resistance from the resistant parent, Wild Brazil. The Pernambuco variety also gave evidence of resistance to injury as compared with the susceptible Smooth Cayenne.

Shamel, of the Department, has studied bud variation in the pineapple in Hawaii (1921,1924–25) and has made one outstanding selection, an Improved Smooth Cayenne strain (*105*). This strain is characterized by uniform size and shape of fruits and is well adapted for canning purposes. Four inferior strains were also discovered and are described in table 4.

TABLE 4.—*Bud variations in the Smooth Cayenne pineapple discovered by Shamel in 1920*

Strain	Characteristics	Remarks
Superior:		
Improved Smooth Cayenne.	Uniform size and shape of fruits; adapted for canning.	Used by California Packing Corporation, Hawaiian Pineapple Co., Libby, McNeill & Libby, and others in Hawaii. Developed through systematic bud selection.
Inferior:		
Small-diameter fruit	Very small slender fruit; large crown and excessive number of slips; rank growth.	Largely eliminated through systematic selection of plants for propagation.
Multiple crown	Very large misshapen crowns	Do.
Prominent-eyed fruit	Rough, coarse fruit	Do.
Collared slips	Small fruit with irregular base	Do.

Johnson (*50*) is carrying on extensive progeny selection work for the California Packing Corporation, and his results fully substantiate Shamel's views on the value of bud selection with the pineapple. Sayed (*101*) has reported on chimeras in pineapple.

Pineapple Improvement in Foreign Countries

At the Low Temperature Research Laboratory, Division of Plant Industry, Union of South Africa, Pretoria, investigations have shown that pineapples with large flat "fruitlets" stand up under storage and transportation conditions much better than others. After doing considerable selection work in commercial pineries with the object of selecting strains showing these desirable characteristics, it was found that very few if any of these selections came true to type; so that a program is now carried on by J. D. J. Hofmeyr, research horticulturist at the Nelspruit station, that has as its object the crossing of several varieties of pineapple in order to produce new varieties with improved keeping and transport quality. This work is in its early stages. Many seedlings from crosses have been produced, but none has yet reached the bearing stage.

W. D. R. Olds, director of agriculture of the Straits Settlements, Kuala Lumpur, reports that a certain amount of improvement work has been started recently on pineapples with the object of improving local varieties for canning. The work includes maintaining, by bud

selection, good quality clones of the Singapore, the local canning variety, and also hybridization work with other local varieties.

In Mexico the principal varieties grown are the Esmeralda, Principe Alberto, Cayena (Cayenne) Blanca, Reina, Enville, and Espanola Roja (Red Spanish). Pineapple investigations are carried on at the experiment stations at Jalapa, Vera Cruz; Acapulco, Guerrero; and Oaxaca, Oaxaca. In the program of selection search is being made for varieties resistant to attack by *Thielaviopsis paradoxa* (DeSeyn) Hoehn., the most common fungus causing decay in Mexican pineapples.

Cytology of the Pineapple

Collins and Kerns (*14*) established the haploid chromosome number for seven varieties of pineapple, including Smooth Cayenne, Queen, Ruby, Pernambuco, and Spiny Guatemala, as 25. Heilborn (*32*) discovered a triploid pineapple clone which was sent to him from South America, and Collins (*13*) found the Cabezona variety to be a triploid. The information on chromosome number in pineapple is summarized in table 5 of the appendix.

In the hybridization experiments in Hawaii, as reported by Collins (*13*), some triploid individuals have been identified in the progeny. The triploid hydrids between *Ananas composus* Merr. var. Cayenne and *A. microstachys* are larger than the diploid hybrids and show predominantly Cayennelike characters. The evidence indicates that the triploids contain 50 chromosomes from Cayenne and 25 from *A. microstachys*.

PAPAYA

The papaya (*Carica papaya* L.), along with the avocado and the pineapple, is one of America's contributions to horticulture. The early explorers were prompt to recognize the merits of this "tree melon", and its culture spread rapidly throughout the Tropics along the trade routes to Asia, Africa, Australia, and the Pacific islands (*91*). The numerous seeds produced by the fruit made its prompt dispersal easy. Popenoe (*91*) states that as early as 1596 the Dutch traveler Linschoten reported from India:

> There is also a fruite that came out of the Spanish Indies, brought from beyond ye Philipinas or Lusons to Malacca, and brought hence to India, it is called papaios and is very like a mellon * * * and will not grow but alwaies two to-gether that is male and female * * * and when they are divided and set apart one from the other then they yield no fruite at all.

The name papaya is believed to be a corruption of the Carib "ababai." The English name "pawpaw", which is still used in the British Empire, has the disadvantage of confusing this fruit with that of *Asimina triloba* Dunal, the hardy pawpaw native to the southeastern part of the United States. The papaya is now widely distributed. Besides being one of the common fruits of tropical America, it has assumed great importance in Hawaii and scarcely less rank in India, Ceylon, Africa, Australia, and throughout the Malay Archipelago.

From the standpoint of production in a brief period from seed it is practically unrivaled among fruits, as seedlings may come into heavy bearing during the first year and bear several successive crops under favorable conditions. The better varieties are worthy rivals of the

muskmelon. Recognition of its outstanding merit has been delayed in some regions by the toleration of inferior varieties. In subtropical areas its tenderness to cold and the hazards of wind and water damage have retarded progress in establishing a stable papaya industry. The importance of the papaya in the food economy of millions points to the duty of the subtropical horticulturist to select varieties best suited to meet existing conditions and to improve and stabilize them by modern breeding methods.

The Cultivated Papaya and Its Relatives

The forms of papaya usually cultivated belong to the species *Carica papaya* of the Caricaceae. The exact origin of this species is not definitely known, but it is supposed that it has originated as a cross between some of the species of *Carica* native to Mexico. According to Solms-Laubach in his monograph on the Caricaceae, the most probable place of origin is Mexico and Central America, and the cultivated type is the product of the fusion of several wild species. As is the case with Indian corn (*Zea mays* L.), the cultivated form has not been discovered in the wild.

There are also other species native to the Andes Mountains of northern South America at elevations of 8,000 to 9,000 feet—*Carica quercifolia* (St. Hil.) Solms, *C. candamarcensis* Hook. fil., *C. pentagona* Heilb., *C. cauliflora* Jacq., *C. hastaefolia* Solms, and others. The commonly cultivated lowland form is fairly tender and cannot withstand temperature much below the freezing point. The Andes Mountain species are quite hardy, and *C. quercifolia* has withstood temperatures below 24° F. in central Florida. The fruit of the lowland type has fairly thick flesh and is very much like the muskmelon in structure. Fruits of most of the mountain types are more or less intermediate between the papaya and the granadilla (*Passiflora*), being fairly small as a rule with flesh that is not very thick. Some of these species are cultivated by the natives of the Andes and are utilized as stewed fruits. Up to the present time the varieties of *C. papaya* are the only ones that have attracted much attention outside the habitat of the hardy species, but, as will be shown later, the mountain species are important from the standpoint of breeding and are now being used in hybridization work.

Carica papaya is a giant semiwoody evergreen plant, which may grow to a height of 25 feet, and as a rule bears no lateral branches unless it is topped. The mountain species, however, are more woody in structure, and lateral branching is more often encountered. Some are deciduous under subtropical conditions. The species of *Carica* are normally dioecious (producing pollen-bearing or staminate flowers and ovule-producing or pistillate flowers on different plants) and bear the flowers in the uppermost leaf axils. The staminate flowers are sessile (short-stalked) on pendent clusters 3 feet or more in length, and the pistillate ones are subsessile and usually solitary or in few-flowered clusters.

In the United States the papaya has been planted in Florida, Texas, and California. In Florida it has escaped to the wild and grows in profusion on the keys, and it is entirely successful as a cultivated plant in the southern part of the State except that in frosty years it

is killed to the ground. In the lower Rio Grande Valley of Texas it is fairly successful but is destroyed during frosty years. In California its outdoor cultivation is hazardous even in the most protected situations, but recently it has been grown under greenhouse culture.

The papaya is most commonly used as a breakfast or dessert fruit, and it is served in halves like the muskmelon in northern countries. It is often used also as a salad, or it is crystallized with sugar. In the immature state it may be served as a cooked vegetable. Other uses include pickles, preserves, jellies, pies, and sherbets. Recently a delightful juice preparation has been made from the pulp.

An active enzyme, papain, is present in the latex or milky juice of the papaya plant and the immature fruit and has become an article of commerce. Papain has properties similar to pepsin and is used internally as an aid to digestion. In the Tropics its digestive action has long been understood, for it is a common practice to rub the juice over meat to make it tender, or, in preparing a fowl, to wrap it in papaya leaves and let it so remain overnight before cooking.

Papaya Improvement in the United States and Its Possessions

The Department has introduced a great many strains of *Carica papaya* and other *Carica* species from various parts of the Tropics and sub-Tropics, and numerous importations have been made by private individuals at various times. From these importations the varieties or strains grown at the present time in the continental United States have originated. In addition to the usual sex forms, pistillate and staminate, many intermediate forms also occur. Some years ago a so-called hermaphrodite strain was extensively planted in Florida, but this was not, strictly speaking, a hermaphrodite, as it segregated profusely in the direction of the dioecious form and various intermediates. In the hands of the average grower the strain rapidly deteriorated. This and other strains were also introduced into the lower Rio Grande Valley of Texas and into California.

The usual dioecious flowering habit of the papaya favors cross-pollination, and it is natural that the common strains should have a mixed inheritance, so that it is difficult to grow a standardized crop for market. The less desirable or even worthless types that appear as individual segregates are a distinct financial loss to the grower. Papaya breeding work was undertaken in order to overcome these handicaps in Hawaii, first by Pope and later by Higgins and Holt; and in the Philippines, first by Wester and later by Torres, De Leon, and Galang. The breeding work of the Department, under the leadership of Traub and Robinson, was undertaken in 1932. More recently (1935) a papaya breeding project has been undertaken by Beaumont and his coworkers at the Hawaii Agricultural Experiment Station.

Hawaii and Canal Zone

The ideals in papaya breeding vary slightly in different production regions. Higgins and Holt (*37*) have outlined the desirable characters in breeding the papaya for Hawaiian conditions:

(1) A vigorous tree; (2) early and low fruiting habit (there is a variation that ranges from fruit hanging almost in contact with the soil to fruit 6 feet off the

ground and this character has been shown to be transmissible); (3) freedom from branches, since branching means pruning and takes nourishment that should go to the fruit; (4) productivity, but not excessive bearing habit—there should be no long bare spaces, nor fruit so numerous as to crowd; the fruit should be well spaced; (5) hermaphroditism would be best if practicable; (6) suitable size in fruit—for table use, medium size; for stock fruit or papain, large size; (7) yield of papain might be increased by breeding; (8) uniformity of shape to facilitate packing—(a) long, tending to cylindrical, for hermaphrodite, (b) ovoid for pistillate; (9) uniformity in ripening, with no "regional" ripening; (10) color should develop before softening—some fruits ripen with very little coloring while others acquire a beautiful golden yellow when still hard and may be kept for several days; (11) color of flesh—pale whitish flesh must give way to yellow, pink, or red; (12) placentae (seed strands) must be easily removable without marring the flesh, should not adhere tightly to inner portions or be more or less buried in the flesh; (13) specific flavors can be transmitted, which makes it possible to establish varieties of high quality, though such quality characters are hard to describe; (14) keeping quality is fairly developed in some types.

Higgins is of the opinion that the hermaphrodite form can be established and recommends also that crosses be made with the various species.

The chief strain grown in Hawaii is the Solo, which has been described by Higgins (*36*). However, according to Pope (*85*), in 1930 the strain had not been maintained by inbreeding and had changed somewhat from the original form during the previous 10-year period. It is described as a dioecious strain without any hermaphrodite individuals, although the hermaphrodite form is said to have predominated in the Solo strain 10 years before. The plants are small and the trunk thin. They usually require 18 months' growth from seed to mature fruit. The fruits do not set as low as in some other strains but begin to develop about 3 feet or still higher above the ground. They are small but numerous. The yield per plant is said to be abundant, but not equal in weight to that of plants of the larger fruited kinds. The Solo fruits weigh 10 to 16 ounces and are mainly of two shapes, pear-shaped and spherical. The two forms occurred separately on different plants for many years at the Hawaii station, but lately it has not been uncommon to find them more or less mixed on the same plant. The skin is smooth and free from blemishes and decaying spots, which occasionally are found on other kinds of thoroughly ripened papayas, and is bright yellow to orange in color. The flesh is of medium thickness, rich golden yellow, smooth, tender, and of a sweet and cresslike flavor.

In the Canal Zone the Solo variety is also the important one. Under date of June 27, 1936, Lindsay writes:

The importance of the Solo variety, not only because of its own excellence but because of its possibility as genetical material, has given rise to several attempts to establish the variety at these gardens. Its characters worthy of note are (a) superb flavor, perhaps excelling all other known varieties; (b) excellent texture of flesh—unsurpassed by any other; (c) high percentage of choice flesh—can be eaten to the skin; (d) good, yellow color of skin before fruit is fully ripe, while most varieties must be harvested and marketed while showing only the first suggestion of yellow coloring; (e) easily separable placentae, making possible the removal of the seed without marring the fruit for serving.

The undesirable characters of the Solo variety are its slow rate of growth, its comparatively low tonnage of yield, and its susceptibility to attack of the papaya fruit fly. The attempts made to permanently establish the Solo variety of the papaya at the Canal Zone Experiment Gardens have indicated that it is very susceptible to cross fertilization and disappears by hybridization if exposed

to other pollen. In Panama, the Philippines, Cuba, and Africa, although first-generation fruits have been excellent and typical of the variety, later generations have exhibited a decided tendency to deterioration.

The Hawaii Agricultural Experiment Station (*31*) reports that floral and fruit studies of the papaya as a preliminary to breeding work are in progress. With the Solo strain, which is the favorite type for planting, less than one-third were found to be entirely female, the remainder exhibiting varying degrees of hermaphroditism. Selected types are being self-pollinated and suitable crosses are being made to determine whether different types may be fixed.

Philippine Islands

In the Philippine Islands, J. P. Torres, J. de Leon, and F. Galang have carried on papaya breeding since 1914 at the College of Agriculture, Laguna. The first attempts were directed toward the isolation of hermaphrodite races through hybridization and selection. It was not found practicable in these first attempts to secure such a race from seedling propagation, but improved types have been selected and distributed for propagation. Work with self-fertilized lines, begun in 1930, is still in progress; renewed effort has been directed toward securing pure hermaphrodite strains, but the progeny thus far have produced hermaphrodite and female plants in varying proportions.

Continental United States

In the early years of the twentieth century, Edward Simmonds, of the Department, attempted to perpetuate desirable clones by grafting in southern Florida, but the method, while successful in individual cases, did not prove adapted to commercial practice. Stambaugh, also in southern Florida, attempted to fix the hermaphrodite character in a purple-stem strain, an introduction by the Department from Panama. Later, in the 1920's and early 1930's, he introduced this strain into the lower Rio Grande Valley of Texas, where other strains had been established at Weslaco, at Substation No. 15 of the Texas Agricultural Experiment Station.

Bronson Bayliss, of Miami, Fla., in the 1920's secured various papaya strains, including two from Hawaii introduced by the Department. He crossed a female form grown from seeds distributed by the Department with a male secured from another source as a basis in developing an outstanding variety, which he named Betty. The growth habit and fruit type have been fairly well maintained by sib pollination [8] through a number of generations, a practice still in progress. The Betty variety (fig. 11) is characterized by a dwarf to medium tree, as grown under Florida conditions. It is an early-bearing variety, and the fruit begins to set very low, sometimes a foot from the ground; it is the direct opposite of the Hawaiian Solo strain in this respect. The fruits are oblong, medium in size, 2½ to 3 pounds, slightly ribbed, flesh moderately thick, color forming usually somewhat irregularly as the fruits ripen; the skin occasionally subject to blemishes and decaying spots; rind and pulp rather soft; dessert quality excellent. The chief defect is its lack of keeping and shipping quality, which can apparently be overcome by crossing with types having hard rind.

[8] The mating of siblings, i. e., pistillate and staminate individuals of the same parentage.

From the standpoint of the continental United States and other subtropical regions, the following objectives in papaya breeding are of primary importance: (1) Relatively thick flesh to increase resistance to the papaya fruit fly; (2) the fixing of a relatively small fruit type (1- and 2-pound sizes) suitable for shipment, having a pleasing flavor and aroma; and (3) crossing *Carica papaya* with the relatively more

Figure 11.—**Typical plant of the Betty variety of papaya, 10 months from seed, grown under irrigation on low hammock soil of Manatee County, Fla. The variety is semidwarf in habit, is noteworthy for precocity, and sets its crop close to the ground, 12 to 18 inches under favorable conditions. Height of plant 5 feet to terminal bud.**

frost-resistant mountain species in order to increase the hardiness of cultivated varieties.

It is also desirable to develop types for shipping that have a hard rind. In this case maturity cannot be judged by softness of rind nor in many cases by yellow skin color. A criterion for degree of ripeness not dependent on color or softening of skin has been developed by Traub, Robinson, and Stevens (*127*), namely, the stage at which the latex exudate from a fruit ceases to be milky and becomes clear or only slightly cloudy. At this stage fruits may be harvested for market without loss of quality.

The fruit of some of the mountain species is characterized by an aroma similar to that of the granadilla (*Passiflora*), and this presents the possibility that this pleasing aroma may be transferred to the cultivated papaya by appropriate crosses.

The breeding project, under the leadership of Traub and Robinson, is concerned with two main objectives—to produce pure lines with desired horticultural characters by inbreeding, and to increase frost

resistance by hybridization between *Carica papaya* and the hardier Andean Mountain species.

The inbreeding work has been carried on since 1932 and consists mainly of selection within sib-pollinated lines in the dioecious form. The hermaphrodite forms are being studied as to their possible value, but up to the present it appears that these are unstable and that the dioecious flowering habit is the normal stable form of *Carica papaya*. The tree habit, fruit shape, and quality have been fairly well fixed in the selected lines of *C. papaya*, and the hard-rind character is being combined with these by crossing. The hard-rind character is positively correlated with resistance to certain storage diseases.

Varieties with the desired tree and fruit characters are being selected in fruit sizes averaging 1, 2, 3, and 6 pounds. The first three types are for dessert purposes and suitability for shipment, but the fourth, averaging 6 pounds, is a dual-purpose variety for use in papain production as well as for dessert use when a large size is desirable.

Papaya Improvement in Foreign Countries

In Mexico the papaya is widely grown, production being estimated at 4½ million pounds a year. The fruits mature principally from October to February. The chief variety is the Chichona, a dwarf type. G. Gandara, of the Mexican Department of Agriculture, reports that selection studies are in progress at the experiment stations at Jalapa in the State of Vera Cruz and at Coalan del Rio, Morelos.

In the Union of South Africa, selection and hybridization with the papaya have been carried on at the Nelspruit Horticultural Research Station by J. D. J. Hofmeyr since 1930, with special attention to inbreeding by sib pollinations since 1933. Pedigree selections have been developed from the Ceylon variety but have not yet been introduced into commercial culture. In hybridization studies the hermaphrodite form is usually used as the male parent. Correlation studies have shown positive correlation between vigor of plant and yield but no correlation between vigor and (1) height at which first fruit is produced and (2) date of ripening of first fruit. The breeding results to date indicate the importance of hand pollination in standardizing fruit type and quality, since any open-pollinated fruit may receive pollen from several males of different genetic character.

In India, B. Nazareth, superintendent of Modi Bag Garden, College of Agriculture, Poona, reports that variety improvement has been sought chiefly by mass selection from numerous seedlings. Crossing experiments begun in 1908 to secure a race of papayas with a large proportion of female plants (using pollen of a hermaphrodite on a pure female type) were carried through two generations. The conclusion was reached that "it seems impossible to fix femaleness in this manner." A variety known as Washington has been distributed recently, excelling local varieties in quality and yield and having a more pleasing aroma.

In Java, Ochse (*80*) states that large-fruited kinds are usually watery and insipid and that the long cucumberlike fruits are among the best in the Netherland East Indies. The recommended varieties for Java are Eedja Boonder, Eedja Pandjang, Eetam Boonder, and Eetam Pandjang.

At the Hope Experiment Station, Kingston, Jamaica, L. N. H. Larter, Government botanist, began work in 1934 with the object of breeding commercial papaya varieties resistant to the mosaic disease. Although 30 varieties of *Carica papaya* and a number of other *Carica* species have been tested, only *C. cauliflora* has proved immune to this disease so far. Crosses have been made between the best commercial strains of *C. papaya* and *C. cauliflora*, but no definite results have been secured up to the present time. The related cytological studies include somatic chromosome counts of the parental types.

Technical Factors in Papaya Breeding

Sex changes of *Carica papaya* have been studied by a number of workers. As early as 1908 Iorns (*48*) reported on sex change in *C. papaya* in Puerto Rico, and since that date various sex forms have been reported and described (*99*), but, as already indicated, the papaya is normally dioecious, and this is the most important form. Its usual expression includes a completely female type, and an almost completely male type that may sometimes produce an inferior fruit only at the end of the inflorescence.

Not only do the sex forms vary in *Carica papaya*, but sex changes from male to female on individual trees and vice versa have been observed (*8*, *48*, *58*, *93*, *100*). In some of the reported cases the sex change was apparently unstable. For instance, a male plant that went through eight sex changes was reported by Kulkarni (*58*), and a tree that "completed the whole cycle of sex and came back to its original condition in its own time" was reported by Burns (*8*). In the experience of Higgins and Holt (*37*) a change once established tends to persist. The cause of the change has not been investigated, but it has been pointed out by Mendiola (*67*) that it could hardly be due to bud mutations or there would be some variability in sex among the branches of the tree (some trees having 15 to 20 branches), and no such variability has been observed in the Philippines.

The change in sex form has been reported to consist in the appearance of functioning pistils on trees previously producing only staminate flowers. In this manner hermaphrodite flowers may develop. This change is said to occur most frequently in regions of cool climate (*58*). The development of female flowers on a male plant as a result of the removal of the terminal bud has also been observed by Reyes (*93*) and others. Neither chilling nor topping can be depended upon to produce the result.

The subject of sex ratios in *Carica papaya* has been studied by various workers. Pope (*85*) has studied the possible effect of the position of the seeds in the fruit as influencing sex and has found no such influence. A preliminary test of this positional influence on sex of seedlings, including three different strains, made by Department workers in 1935, has given similar negative results. Work by Traub and Robinson has shown that in a population of sufficient size the normal expectation of 50 percent in each sex form is generally realized in strains purified by selection within sib-pollinated lines. The recommendation to set two plants in a hill in order to secure the required stand of female plants is based on these results. However, Hofmeyr (*40*) in South Africa advocates the use of four plants to a

hill for open-pollinated strains. Morphological leaf characters and vigor of growth have proved of no value in sex prediction (*58*).

Work carried on by Traub and O'Rork in 1936 shows that papaya pollen can be stored over a considerable period under the proper temperature and humidity conditions. At approximately 10-percent humidity and 34° F., pollen remains viable for many months. When this report was submitted, pollen stored as indicated was still viable after 7 months. Storage at room temperature and under other unfavorable conditions results in a rapid fall in germination. The pistil remains receptive for a number of days. Pollinating shortly after the flowers opened gave somewhat higher percentages of fruit setting than was the case when this operation was carried out either shortly before or 3 to 4 days after the flowers opened.

Pollination in the papaya is very easily controlled. The flower is large, and the pollen is easily transferred from staminate flowers just about to open, or stored pollen may be used. The unopened pistillate flowers are bagged a day or two before the flower opens. For this purpose a ¼-pound brown paper bag is used. It has proved more successful than cellophane bags, which retain moisture and raise the relative humidity unduly high. Before the bag is applied any side flowers are cut away, leaving only the central flower. When the flower opens, which is in a day or so, pollen is applied, the flower is rebagged, and the bag is left on for several days until the petals fall and the fruit begins to enlarge.

It is generally recognized that fruits may sometimes develop without pollination, usually when the plant is growing vigorously. Such seedless fruit is invariably of poor quality and relatively small in size. In many instances the flowers that are not pollinated drop soon after the petals fall. Fruits are sometimes found in which seeds are produced in only one portion of the fruit (the stylar end). This seedy portion is more fully developed and of better flavor than the seedless part. Such partial seedlessness is apparently due to deficiency in number of pollen grains reaching the stigma, or possibly to lack of pollen vigor.

Inheritance Studies and Cytology

Practically no detailed inheritance studies with papaya have been made. Hofmeyr (since 1933) has made a study of progenies of sib-pollinated fruits as a basis for comparing the relative potentialities of the staminate trees (*40*). He found great variation in the thickness of the fruit flesh, shape and size of fruit, unit volume, weight and nature of the seed cavity of fruit, and other fruit characters. The breeding work with papaya carried on by Department workers in Florida since 1932 is similar in nature. The parental lines selected for breeding are being purified by sib pollinations through several generations in order to secure lines that breed relatively true for the desired horticultural characters. These elite forms will then be used in crossing to secure desirable recombinations in the F_2 (second hybrid) generation.

Higgins and Holt (*37*) put forth the hypothesis that the dioecious varieties of the papaya cannot be maintained in a stable condition, since—

> seed from a pistillate tree will necessarily be a cross between two individuals. The characters of the female plant may be known, but those of the male plant are

utterly unknown. The parent stock from which both come may be known, but since there is wide variation in the fruit of two pistillate trees from the same stock, it is reasonable to suppose that there will be the same wide variation in the male or staminate trees * * * the process of producing a stable variety of good qualities by the use of this dioecious type would be extremely long and tedious.

This same hypothesis is repeated by Mendiola (*67*) and again by Pope (*85*). In the light of recent accomplishments utilizing selected dioecious types, line-bred by sib pollination, this hypothesis need no longer discourage breeders and retard progress in developing stable varieties of superior papayas. The work carried out by Department workers since 1932, and by Hofmeyr in South Africa since 1933, shows that the desired horticultural characters can be fixed and maintained by selection within sib-pollinated lines of the dioecious form of *Carica papaya*.

The chromosome counts recorded for the various species of *Carica* give uniformly 9 for the haploid number. Determinations by Heilborn (*33*) for *C. papaya*, *C. candamarcensis*, *C. chrysopetela* Heilb. and *C. pentagona* Heilb., and by Neruman in 1925, Sugiuara in 1927, Asana and Sutaria in 1929, and Lindsay in 1930 for *Carica papaya*, are indicated in table 5 of the appendix.

MANGO

The mango is one of the oldest of cultivated fruits, and not many fruit crops have a similar historical background. In 1556–1605, at a time when there were no extensive orchards, the Mughal Emperor, Akbar, planted in northern India a grove of some 100,000 mango trees. The horticulturist Charles Maries found some survivors still in a thrifty condition 300 years later (*91*). Through centuries of mass selection many choice varieties were accumulated, and the progress made can be evaluated by a comparison of the choice oriental grafted varieties with the worthless fibrous seedlings having a strong turpentine flavor that represent the ancestral stock.

According to De Candolle, the native habitat of the mango is undoubtedly the general region of southern Asia and the Malay Archipelago. The mango belongs to the species *Mangifera indica* L., which is a member of the family Anacardiaceae. Several of the 40 or more species of *Mangifera* besides the mango are cultivated for fruits, although on a minor scale.

The following characterization of the tree and fruit is in part quoted and in part adapted from Popenoe (*91*), a recognized authority on this fruit:

The mango is an evergreen tree, often reaching immense size and great age. Growth is not continuous throughout a long season, but is characterized by frequently occurring flushes of growth. The small pinkish white flowers are borne in large panicles at the end of the branchlets. In Florida and the West Indies the flowering season extends from December to April. Sometimes the trees bloom two or three times during the season. More than 4,000 flowers have been counted on a single panicle, but not all of these are capable of developing into fruits, since the mango is polygamous, that is, it produces two kinds of flowers—perfect ones having both stamens and pistils, and others that are of one sex, staminate. The latter commonly outnumber the perfect flowers. Usually there is only one pollen-bearing stamen in each flower. The perfect blossoms are easily distinguished from the staminate ones by the presence in the former of the small greenish-yellow ovary surmounting the white disc in the center.

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The fruit varies greatly in size and character. The smallest kinds are no larger than good-sized plums, while the largest are 4 to 5 pounds in weight. The form is oval, pear-shaped, kidney-shaped, round, or long and slender. The skin is smooth, thicker than that of the peach, commonly yellow on the surface but varying greatly in color. Some varieties are delicately colored, deep yellow or apricot with a crimson blush on one cheek; others are an unattractive green. The color depends to a certain extent on the climate. The aroma is often spicy and alluring, indicative of the flavor of the fruit. The flesh is yellow or orange in color, juicy, often fibrous in seedlings and inferior budded varieties, but in the best sorts entirely free from fiber and of smooth melting texture. The seed is large and flattened, its tough woody husk or outer covering enclosing a white kernel. The flavor of the mango has been likened to a combination of apricot and pineapple, but this comparison does not describe it accurately. It is rich and luscious in the best varieties, sweet, but with sufficient acidity and spiciness to prevent its cloying the palate.

Races and Varieties

As already indicated, the superior mango varieties have originated locally through centuries of natural selection. However, vegetative propagation was not practiced as a rule, and in the various regions of mango culture, as in the Philippines and Cambodia, races breeding fairly true to type from seed have gradually developed. This condition is favored by the presence of nucellar embryony[9] (*3*) in certain races of mangoes. These seedling races, therefore, should be distinguished from strictly horticultural varieties, which are propagated by grafting and budding, and some of which, including the better Indian varieties, do not produce nucellar embryos. The seedling races have not been extensively studied, and they present a promising field for the plant investigator.

Although the seedling races reproduce the racial characters with fair constancy, there is enough variation among them to make some more desirable than others. Some of these, such as the Cecil and Cambodiana in Florida, have been vegetatively propagated and thus have become horticultural varieties.

The classification of mangoes has been discussed by Burns and Prayag (*9*), Rolfs (*98*), and Popenoe (*91*). The abundance of grafted mangoes has led East Indian investigators to neglect the seedling races, which are less important in that country, though they are the most important elsewhere in the Orient. The horticultural varieties of mangoes are very numerous, numbering up to nearly 500. Of these, however, relatively few are grown to any extent. Popenoe (*91*) grouped the horticultural varieties grown in the United States into four groups based on natural resemblances: The Mulgoba group (Mulgoba, Haden); the Alphonse group (Amini, Bennett, Pahiri, Rajpuri); the Sandersha group (Sandersha, Totafari); and the Cambodiana group (Cambodiana).

The center of dissemination of the choice mango varieties includes India, Indo-China, and the Philippine Islands, where improved races and varieties were developed through thousands of years of mass selection. Mango culture spread to the tropical coasts of East Africa, West Africa, and Madagascar. The Portuguese apparently brought the mango to the American continent, where it was probably first planted in Brazil prior to 1700. From South America it spread to the West Indies, and it was brought into Mexico in the early nineteenth century.

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[9] See the discussion of nucellar embryony later in this article (p. 887) and also in the article on citrus fruits (p. 794).

The mango was introduced in Australia soon after settlement began, and it thrives in the State of Queensland. In the Mediterranean region mango culture has not been successful as a rule.

Mango Improvement in the United States and Its Possessions

The first mango trees introduced into Florida of which we have record were those brought in by Perrine (*83*) in 1838. These trees, planted on the coastal keys below Miami, disappeared after his death.[10] However, the occurrence of old seedlings of the "turpentine" mango in the Tampa Bay section and on the lower west coast, evidently 50 to 75 years old or even older, indicates that mango seeds were brought in, probably from Cuba, and planted at an early date. Other introductions of improved varieties were made but apparently did not survive.

The Division of Pomology, Department of Agriculture, on November 1, 1889, received a shipment of six varieties from India, which were planted by horticulturists in the vicinity of Lake Worth, Fla. Of these apparently one tree each of the Alphonse and Mulgoba varieties survived, the latter beginning to bear in 1898. The superior quality of its fruit furnished the needed stimulus to the development of mango culture in this country, and considerable numbers of Mulgoba were soon propagated and planted along the lower east coast of Florida. Since that date the Division of Plant Exploration and Introduction of the Department has introduced more than 50 varieties of mangoes from India, Indo-China, the Philippines, and elsewhere, representing a total of 238 introductions of *Mangifera*.

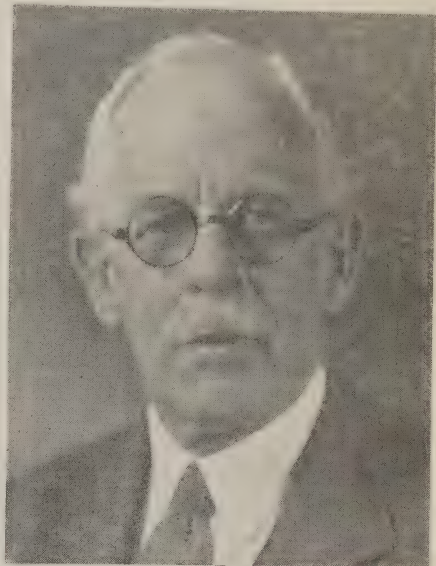

Figure 12.—David Fairchild, who organized the plant introduction unit of the United States Department of Agriculture in 1897 and remained in charge of this service until 1928. Under his leadership germ-plasm collections of many crop plants were introduced; we are indebted to him for more than 50 varieties of mangoes as well as many other subtropical fruits.

Few exotic plants at the introduction stage have had the advantage of the intense interest and enthusiasm exhibited by David Fairchild (fig. 12), who, both as an active explorer and as head of the Division of Plant Introduction, was chiefly instrumental in bringing together this remarkable collection of mango varieties, representing the best

[10] Plantings of mangoes as well as of many other tropical fruits introduced by Perrine from Mexico were confined to the coastal keys, as hostile Indians at that time prevented their being planted on the mainland tract granted by Congress to Perrine in 1838 for tropical plant introduction and colonization. This fact probably accounts for the almost complete disappearance of his numerous introductions, the rock formation on the keys being unsuited to the growing of most fruit trees. His tragic death in the Indian Key Massacre in 1840 doubtless postponed the development of fruit industries in southern Florida for at least half a century.

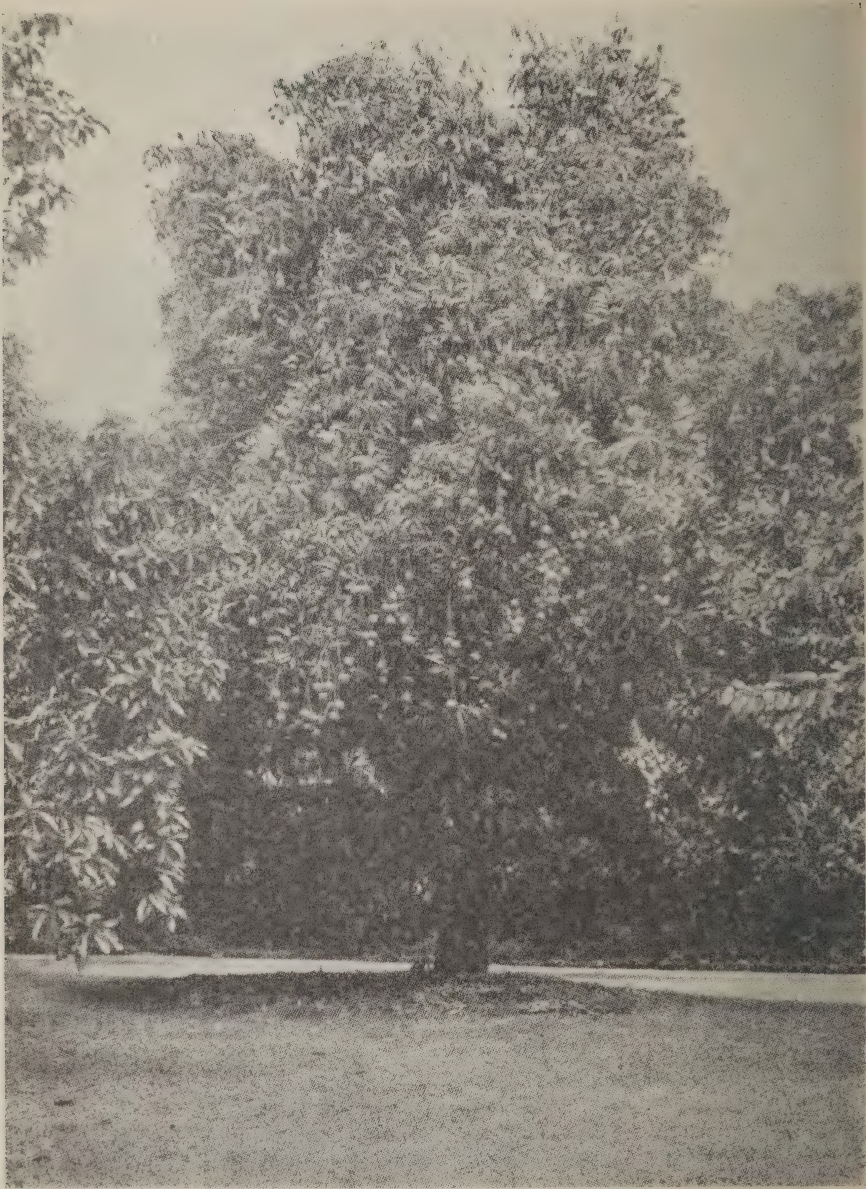

Figure 13.—The original Haden mango tree, a seedling of Mulgoba which was introduced from India by the United States Department of Agriculture. This Florida-grown seedling is the parent tree of fully 90 percent of the commercially grown mangoes in Florida and is being tested elsewhere. Originated by John J. Haden, of Coconut Grove, Fla.; first fruited in 1910; introduced about 1914.

germ plasm available in its known habitats. The utilization of this material offers a most promising field for the plant breeder, including as it does the best varieties of grafted Indian mangoes as well as the seedling races of Cochinchine, Cambodia, and the Philippines, together with varieties developed in the West Indies and South America. In this field of introduction work as well as in numerous other plant groups appreciative mention should be made of the generous cooperation of such men as Barbour Lathrop and Allison V. Armour, who made possible many important introductions.

Since the introduction of the Haden variety (figs. 13 and 14), about 1914, the mango industry in Florida has been based almost exclusively on this variety, which originated as a seedling of Mulgoba. The Mulgoba, in common with practically all of the fine Indian mangoes, had proved not to be dependable in bearing habit. The Haden in addition to bearing at an early age and fairly regularly has fruit with a beautiful red blush unrivaled by any known mango. Its quality is also good and the fiber not objectionable. Its size, from 10 to 18 ounces, and its shape, rounded oval, made it well suited to the commercial requirements, but recently it has come to be regarded as too large for all but the fancy trade. The bearing habit, probably as affected by disease, has not been satisfactory to growers. This has given impetus to the search for better varieties.

E. N. Reasoner initiated the propagation of imported Indian varieties, making several introductions. Cellon and John Beach were contemporary pioneers in mango nursery propagation and made the new varieties available for trial as they showed promise. The late W. J. Krome contributed greatly to the advancement of the mango industry by his discriminating judgment in the testing out of new varieties and working out the best cultural practices under grove conditions.

It is believed that the mango was first introduced into California in 1880–85, but the tree does not seem to be well adapted to conditions in that State. The hardier varieties from northern India may be more suited to southwestern climatic conditions, but these are not at present available.

Hawaii

The mango was introduced into Hawaii in 1824, seedling plants being brought from Manila (*69*). This early introduction gave rise to a race of seedlings locally known as the Hawaiian race, similar in seed polyembryony and other characteristics to the Philippine race. More recently introductions of Indian and other mango varieties by the Department and by private individuals have raised the standard of good mangoes in Hawaii. The mango found a congenial home in Hawaii and has long been one of the most important fruit crops grown there. Fruits ripen from April to November, from successive flushes of bloom.

In Hawaii, as in Florida, many of the most promising varieties are selections from locally produced seedlings, few of the imported varieties proving entirely suited to environmental conditions. In selecting varieties for commercial planting consideration has had to be given not only to resistance to bloom blight but to the attacks of the Mediterranean fruitfly. Many of the seedlings from seed produced in mixed variety plantings give evidence of hybrid origin. Pope (*84*)

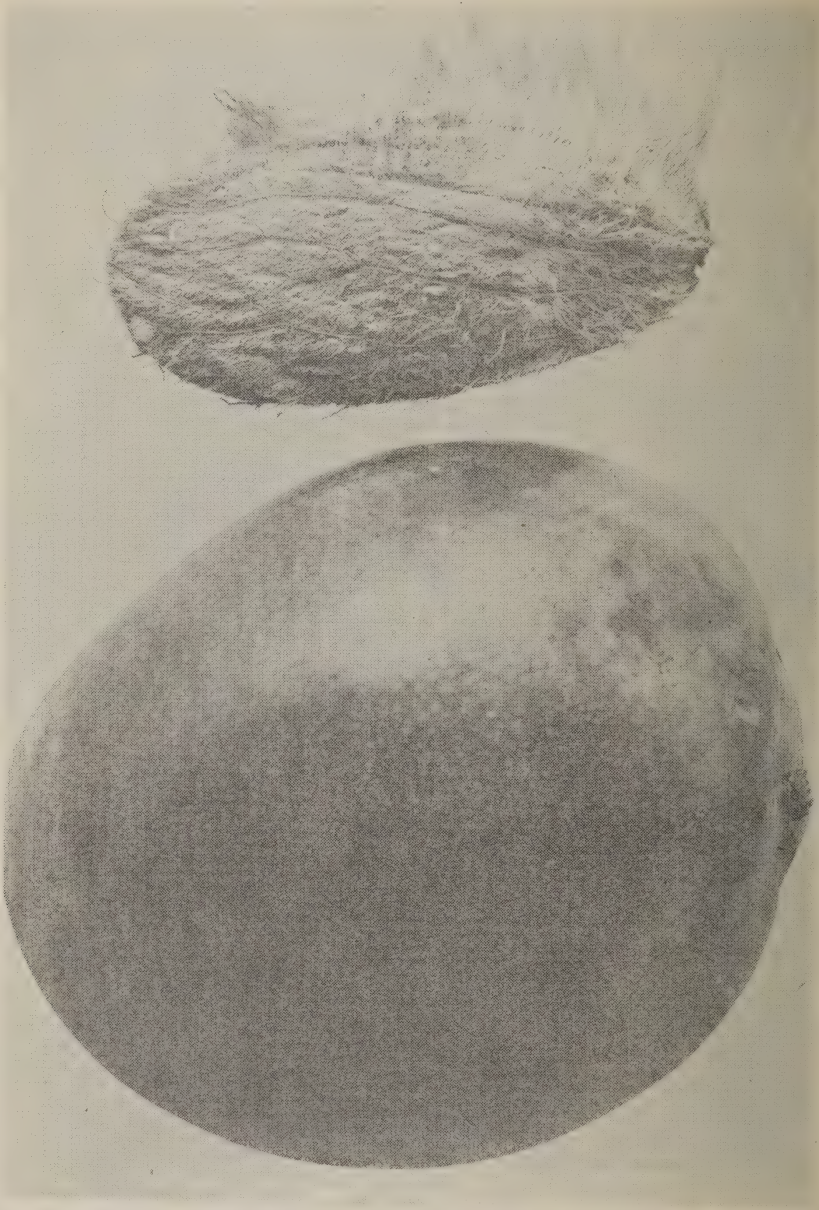

Figure 14.—Haden mango fruit. Originating as a seedling of the Mulgoba, the Haden is outstanding among all mangoes for its brilliant crimson color combined with good quality.

lists 51 varieties as being under cultivation in Hawaii, about half of which are of minor importance.

The varieties that have proved outstanding for resistance to fruitfly attack, satisfactory production, and fruit quality are Wooten, Roberts,

Steward, No. 9, and Holt. Among the introduced varieties the Pirie (Paheri) has proved less susceptible to fruitfly attack than many other varieties and is now the most extensively grown of the East Indian varieties. A seedling of the Pirie, called the Davis, has thus far shown freedom from fruitfly attack and has much of the quality of the parent variety.

Canal Zone

The mango tree thrives under the climatic conditions of the Canal Zone, but, as in most humid regions, fruiting of the better introduced varieties has been unsatisfactory, owing largely to fungus attack, which affects the bloom and also causes fruit loss during the ripening period. Selection for resistance to anthracnose (caused by *Colletotrichum gleosporoides* Penz.) has therefore been of paramount importance.

Outstanding among the selections to date is one originating as a seedling of the Saigon group, which has been called the Fairchild "in honor of the distinguished explorer to whom credit is due for the introduction of the seed from which all of these varieties have sprung" (*36*). Trees of this variety are reported as vigorous and productive, the fruit free from fiber and of delicious flavor, excelling all others in resistance to mango anthracnose. Next in rank is placed the Pairi (Paheri) variety.

Puerto Rico

The mango is very well adapted to Puerto Rico, and it is the characteristic fruit tree in all parts of the island. Although the improved varieties imported by the Department were also tried out in Puerto Rico, the trees are usually seedlings and represent a number of types, some of which are of superior quality. During the last 2 years an extensive program of top-working inferior seedlings to improved varieties in the extensive collection of varieties brought in by the Department at the Federal Experiment Station, Mayaguez, has been in progress.

The variety collection at Mayaguez is being intensively studied with the object of singling out desirable types for propagation. The initial studies by Traub, Carrero, and McAlester,[11] in the summer of 1935, have shown that the Divine variety is resistant both to anthracnose and to fruitfly infestation. Amini and Cambodiana are outstanding from the standpoint of yielding capacity. Sandersha and Sufaida show a tendency for the stylar end of the fruit to become overripe before the basal part is mature, and as a result of such uneven ripening they are severely infested by the West Indian fruitfly.

Philippine Islands

In the Philippine Islands the mango takes first rank among the many fruits grown (*136*). Seedlings predominate, and among these there is a general similarity in fruit characters. This uniformity is readily understood when it is recalled that mangoes of the Phillippine race are polyembryonic, producing nucellar embryos that reproduce the mother variety with slight if any variation. This race is recognized as producing fruit of superior excellence though lacking the size and color found in some of the Indian mangoes and hybrids developed from

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[11] TRAUB, H. P., and CARRERO, C. O. MANGO FRUIT MATURITY AND QUALITY. U. S. Off. Expt. Sta., Bur. Plant Indus., and Bur. Ent. and Plant Quarantine. 1935. (In manuscript.)
——— and MCALESTER, L. C. RELATION OF VARIETY AND MATURITY FACTORS TOR ESISTANCE OF MANGO FRUITS TO FRUIT FLY INFESTATION. U. S. Off. Expt. Sta., Bur. Plant Indus., and Bur. Ent. and Plant Quarantine. 1935. (In manuscript.)

them. Wester (*136*) calls attention to eight species of *Mangifera* that bear edible fruits besides *M. indica*, the common mango, namely, *M. caesia* Jack, *M. odorata* Griff., *M. foetida* Lour., *M. altissima* Blanco, *M. sylvatica* Roxb., *M. lagenifera* Griff., *M. langang* Miq., and *M. similis* Blume. All but *M. sylvatica* occur in the Philippines or nearby portions of Malaysia. The cultivated mango was introduced into the Philippines from Siam, but probably not until after 1600.

Selections made from the best seedlings have given rise to a number of varieties, the best known of which are the Carabao and Pico. These, however, are not generally propagated by vegetative means, since they can be depended upon to come true from seed in most instances.

Mango Improvement in Foreign Countries

G. Gandara, of the Mexican Department of Agriculture, reports that mangoes are very widely grown in Mexico, the annual production being estimated at approximately 9,660 tons. The usual period of maturity is from May to July. The principal varieties are Criollo or native seedlings and the Manila, together with many other seedlings of the Philippine type. Mango investigations are under way at the experiment stations of Jalapa, Vera Cruz; Acapulco, Guerrero; and Oaxaca, Oaxaca. Improvement is being sought by grafting the Manila on the Criollo stock, since the former is the best commercial variety and most resistant to attack by the Mexican fruitfly (*Anastrepha ludens* Loew).

R. D. Fordham, deputy director of gardens, United Provinces, Saharanpur, India, reports that mass selection from seedlings of named varieties has given two superior varieties, Partap Special No. 1 and Partap Special No. 2.

B. Nazareth, superintendent of Modi Bag Garden, College of Agriculture, Poona, India, reports that although types with more than one embryo are occasionally met with, the Indian mangoes are known to be typically monoembryonic, resulting in much seedling variation. Vegetative propagation is commonly practiced to insure stability of varieties. The varieties Shahabuddin and Shedrya have been widely distributed because of their vigor of growth and prolific character. The fruits are small and round. Beginning in 1911 a number of attempts were made to secure improved varieties by hybridization, but not until 1915 were any hybrids secured. Of the three hybrids secured, one has fruited but has not been introduced into cultivation.

Methods and Objectives in Mango Breeding

Maheshwari (*61*) has stated that the number of flowers in the mango inflorescence varies from 1,500 to 4,000, and the varieties with the better fruit have the largest inflorescences. On an average two to three fruits are usually set for each inflorescence, although the number sometimes may be as high as six. The flowers that dry up have aborted embryos. From 5 to 10 percent have normal-appearing ovaries, and these occur mostly toward the apex of the inflorescence and are mainly the primary flowers of the little cymes and to a lesser extent the secondaries. A tertiary flower group, or cymlet, almost never produces a good ovary. Flowers open in the afternoon and remain fresh looking until the next day. The stigma is poorly developed, and pollen is largely defective. Insects do most of the pollinat-

ing, but the agency of the wind is not excluded, and gravity fall may be instrumental to a lesser extent. Actual fertilization has not been seen, but the stages near it have been. Alternate bearing is very pronounced in the mango.

Popenoe (*88*) germinated mango pollen in an artificial culture medium of 25 percent of sugar and 0.5 percent of agar. The best germination was secured at a temperature between 75° and 80° F. No germination was secured at 60° or lower, but a few feeble pollen tubes were secured at 65°. Germination begins within an hour, and the maximum pollen-tube growth is reached at the end of 12 to 24 hours. The germination secured averages between 10 and 15 percent. Popenoe found that the pollen germination for all mango varieties studied was very poor.

The breeding work with the mango has been seriously handicapped because no effective method of controlling pollination has been worked out. Of the thousands of individual flowers in the mango inflorescence, only a very small number as a rule set fruit that is held to maturity. Attempts to control pollination by the usual bagging technique have been disappointing, since the percentage of fruits set is exceedingly small or nil. Since pollination in the mango is normally carried out by the agency of insects, the most promising method used so far in Florida is to collect seeds from mixed plantings containing the desired parent varieties. Some of the seedlings secured by this method are exceedingly promising, although they have not been extensively tested out. On the whole the possibility of originating varieties better adapted to American conditions has not been taken advantage of to any extent, although the prospects in this direction are very encouraging.

On the old mango-production regions in the Orient, and also in regions where mango culture was established during ancient times, few attempts are being made to improve varieties by hybridization. In the Orient varieties of excellent quality and well adapted to the climatic conditions were developed through thousands of years of mass selection, and in the newer mango regions the work is concerned mainly with the selection of the better varieties from a large number of introduced clones, or, in the case of the polyembryonic races, propagation by seeds is commonly practiced.

In continental United States and Puerto Rico recently mango breeding programs have been initiated in order to produce varieties better adapted particularly from the standpoint of resistance to diseases and insects.

The work of Traub, Stevens, and Robinson, of the Department, begun in 1933, is concerned mainly with breeding for disease resistance in large numbers of seedlings secured from groves where there is the largest possible chance of cross-pollination. These seedlings are tested for anthracnose resistance, and those that show resistance are usually less than 1 percent of the total.

The outstanding problem confronting the grower in Florida is the notoriously irregular bearing habit of the mango. Apparently this is primarily due to the ravages of anthracnose disease, but such causes as low temperature, relatively high humidity during the flowering season, and lack of pollination may also be operative in some instances. It is true that some of the varieties, such as the Sandersha and Cambodiana, are fairly dependable in bearing. These or similar varieties

should undoubtedly be used in breeding work, since they offer the possibility of imparting this desired character to their progeny.

The Brooks variety, originating as a seedling of the Sandersha, has the regular bearing habit of the parent but lacks the high color desired by the trade and the consuming public. It has considerable promise as breeding material, however, and fulfills fairly well the need for a late-maturing fruit of good quality. Another late-maturing variety, Faizanson, originated by J. A. Felts, Palma Sola, Fla., as a seedling of the Faizan, is being tested out. It is of medium to large size and of regular bearing habit and good quality, but it lacks attractive color.

The American market at the present time demands a red-colored mango, and it is encouraging to note that some of the newer seedlings have this particular character to a marked degree. The red blush not only serves to attract the customer but is also a mark distinguishing the fruit from seedlings or inferior varieties, which commonly lack this color.

The mango varieties now grown in the United States are quite susceptible to frost injury, and there is need to consider the possibility of developing desirable varieties resistant to low temperature by breeding methods. Attempts are being made by the Division of Plant Exploration and Introduction to import mango germ plasm from the northernmost mango regions in India for use in such breeding experiments.

Exploratory work carried out in Puerto Rico by Traub, of the Bureau of Plant Industry, and McAlester, of the Bureau of Entomology and Plant Quarantine, at the Federal Experiment Station, Mayaguez, in 1935 indicates that susceptibility to attack of the West Indian fruitfly in mango is dependent upon the thickness of the skin and the presence of disease lesions, and that at least one variety studied, the Divine, with a remarkably thick skin, was free from anthracnose and consequently was not infested by the fruitfly.[12] Work carried out by Traub and by Carrero, of the Office of Experiment Stations,[13] shows that this variety has high quality although the sugar content is slightly lower than that of the average mango varieties. The skin is relatively thick, smooth, and glossy, with a green ground color and a hydrangea-red (rusty) blush. The flesh color ranges from light cadmium to cadmium. In weight, as in most other characters, it holds an intermediate position (11.7 ± 0.25 ounces). It has a most excellent flavor. Its relatively thick skin and firm flesh character should be of value in connection with keeping quality in storage and transit.

In breeding for Puerto Rico conditions the Divine might well be crossed with such varieties as Amini, Cambodiana, and the most desirable seedlings of Mango del Pais. The latter varieties are of secondary importance because of their susceptibility to anthracnose and fruitfly infestation. Such a program might give rise to a race of mangoes highly resistant to fruitfly infestation and the anthracnose disease, with high yielding capacity and excellent dessert and keeping quality. Most of these qualities are apparently already found in combination in the Divine variety.

In connection with the size of fruit it was noted that regional or uneven ripening of the individual fruit is directly correlated with

[12] TRAUB, H. P., and MCALESTER, L. C. See footnote 11.
[13] TRAUB, H. P., and CARRERO, C. O. See footnote 11.

Figure 15.—Nucellar embryony in the mango, showing eight seedlings sprouting from one seed.

relatively large size. In such cases of uneven ripening the stem end may be green, hard, and immature when the stylar end is already mature or senescent and the intervening region is intermediate in maturity. This is an ideal arrangement to increase fruitfly infestation, since a portion of the fruit is usually overripe and affected with anthracnose lesions and therefore vulnerable to these insects by the time the rest of the large fruit is considered ripe enough for picking. As a rule such large fruits must be picked earlier than they commonly are if severe fruitfly infestation is to be avoided. The breeder should keep these facts in mind when selecting for fruit size.

Investigations in Polyembryony

Belling (*3*) at the Florida Agricultural Experiment Station in 1908 investigated the nature of nucellar embryony in the mango, using the strain or variety No. 11 (fig. 15). He found that the megagamete, whether fertilized or not, never gave rise to any of the embryos in the sac. Webber (*132*), in discussing apogamy in mango with reference to mango root stocks in South Africa, reports that the Peach mango strain in the Transvaal averages two and one-third seedlings per seed and that it is apparently nearly 100-percent apogamous. He states that the variety Sabar is also grown from seed and comes true. Juliano and Cuervas (*51*) studied polyembryony in the Pico variety of mango. In this variety the megagamete normally gives rise to a fertile embryo, which is usually larger than any of the embryos formed from the nucellar cells. The latter are usually two or three in number.

MISCELLANEOUS SUBTROPICAL FRUITS

Of various other subtropical fruits—olive, persimmon, guava, granadilla, jujube, cherimoya, pomegranate, white sapote, etc.—most have received little attention from the plant breeder. Some of these have apparently been highly improved by selection through hundreds of years; others, for example the cherimoya, have been taken over from the wild without much improvement. In some of these fruits a good deal of improvement may be expected in the future.

Olive

A very large number of olive varieties (*Olea europaea* L.) have been introduced into California, including the principal varieties of Spain, France, and northern Italy. Many of these, especially the Italian varieties, have fruit too small to be acceptable in the pickled form and have been in great part abandoned or grafted with larger varieties. Most of the varieties recently planted have consisted of Mission, Ascalano, Manzanilla, and Sevillano, though about 10 or 12 other varieties are still found in commercial quantities. The Mission variety, which is preferred over all others, was introduced by the early Spanish missionaries; Ascalano is from Italy; Manzanilla and Sevillano are from Spain.

In contrast with the Mediterranean crop, which is chiefly pickled in the green stage or pressed for oil, the California crop is mainly marketed as "ripe olives." The gradually mounting production during the last 10 years, from 12,000 to 28,000 tons in California, indicates

the growing importance of this crop. Selection and breeding for fruit size and high oil content may be expected to enhance the value of this highly nutritious fruit in the dietary of the Nation.

Persimmon

The persimmon (*Diospyros kaki* L.) was highly developed by selection during past ages in Japan, China, and Chosen, and the chief varieties were introduced into the United States during the last part of the nineteenth century and first two decades of the twentieth, both by the Department, chiefly through the thorough exploration of P. H. Dorsett, and through private initiative. The American industry is centered chiefly in California and to a lesser extent in Texas and the southeastern Gulf States.

Hume (*44*) has studied the flowering habit of *Diospyros kaki* and has placed the extensive number of varieties studied into three groups—(1) those producing only pistillate flowers, (2) those bearing both pistillate and staminate flowers regularly, and (3) those bearing pistillate flowers and occasionally staminate flowers. Hume also indicated the outstanding value of the variety Gailey as a pollinator for those in the pistillate group. The Tanenashi is the principal variety grown in the upper Gulf coast region, the Hachiya in California. Both belong in the first group and are practically seedless (*11*). A nonastringent type, the Fuyu, offers promise but has not as yet become well known. In Texas the Hyakume, Yemon, and Tanenashi appear the most promising, with the Gailey as a pollinator for the first two varieties.

Noguchi (*79*) found metaxenial effects produced by different pollens used on several varieties of persimmons. According to Noguchi, shape rather than size of fruit was affected; sweetness and astringency were transferred as metaxenial effects.

Yasui determined the haploid chromosome numbers in several horticultural varieties of *Diospyros kaki* as 27, but Namikawa and Higashi have not been able to verify these findings, since their counts gave 45 for the haploid number. These workers counted 15 as the haploid chromosome number in *D. lotus* L., and Hague reports that the haploid number in *D. virginiana* L. is at least 30 (table 5).

Granadilla

The granadillas (*Passiflora* spp.) are natives of tropical America but are chiefly appreciated and cultivated in Australia and South Africa. The fruits are borne on vines supported on trellises and mature a crop within a year or two from seed. The commonly grown purple granadilla (*P. edulis* Sims) has fruit the size of an egg with a crusty, brittle rind enclosing a yellowish aromatic pulp in which are embedded many small seeds. It is chiefly used in ades, fruit punches, and salads. Recently small plantings of the purple granadilla and a few other varieties have been made in California. Workers in Australia have imported *P. incarnata* L. from Florida for use in hybridizing. Through the active interest of W. E. Whitehouse, of the Division of Plant Exploration and Introduction, many species of *Passiflora* have recently been imported especially with a view to providing material needed by plant breeders in this field. The most

valuable are apparently *P. quadrangularis* L., with a large fruit, and *P. ligularis* Juss., with the most delicious flavor found in the genus.

The breeding project carried on by Traub and Robinson, of the Department, is concerned chiefly with a search for nematode-resistant breeding stock, and with the hybridizing of *Passiflora incarnata, P. edulis, P. quadrangularis,* and *P. ligularis.* The objective is to produce hybrids adapted to the southeastern United States, resistant to nematode injury, and with large size fruits of dessert quality equal to *P. ligularis.*

Heintz in 1926 determined the diploid chromosome number in *P. princeps* var. *coccinea* Hort. and *P. coerula* L. as 18 (table 5).

The Hawaii Agricultural Experiment Station (*31*) is carrying on cytological studies with *Passiflora,* and the chromosome numbers of 12 species have been determined. The diploid number was determined as 18 for most of the species examined (table 5). Morphological studies of the chromosomes are being made, and the inheritance of various specific characteristics will also be followed in order to associate the inheritance of species characters with definite chromosomes. A number of interspecific crosses have been made and a fair yield of seed secured.

Guava

The guava (*Psidium guajava* L.) is of almost universal distribution in tropical regions of the world, occurring as a semiwild plant in many places where killing frosts seldom occur. The fruit is variable, from round to pear-shaped, from the size of a small plum to that of a large pear, and from green to yellow. The pulp, which is slightly granular, varies from white to deep pink and has a distinctive odor not always considered pleasant by some. The many small hard seeds are somewhat objectionable when the fruit is eaten out of hand, but most of the crop is utilized for jelly making or preserving and the seeds are strained out in the process. Its ease of propagation from scattered seed has doubtless retarded any program of improvement or the development of standard varieties. With the growing importance of a canning and preserving industry based on this fruit, it has been recognized that a large proportion of unselected seedlings are inferior because of (1) low production, (2) lack of pectin, (3) poor color or texture, or (4) a combination of these faults. Selection of the better types for jelly use or for preserving has been begun in Florida, and a method of bark grafting has been worked out by Smith (*107*) that makes possible the top-working of otherwise worthless seedling trees. This method is adapted to nursery practice with slight modification. Vegetative propagation from root or tip cuttings has also been demonstrated as feasible, with such control of temperature and humidity as is afforded by a solar propagation frame. With such selected and standardized material to work with, breeding methods may be expected to bring about further improvement to meet the needs of the industry.

The Cattley or "Strawberry" guava (*Psidium cattleianum* Sabine) is considerably hardier than the ordinary species and is a favorite for growing in California and the cooler portions of Florida. There are both red- and yellow-fruited forms, the latter often called "Chinese guava." Because of its dwarf compact habit the tree is adapted for

planting as an ornamental as well as for its excellent sprightly flavored fruits. It is more resistant to salinity in the soil than the common guava.

Some other species of *Psidium* may prove useful in future breeding, as *P. friedrichstahlianum* (Berg) Ndz. (very acid), of Costa Rica, and *P. molle* Bertol., of Guatemala.

B. Nazareth, superintendent of Modi Bag Garden, College of Agriculture, Poona, India, reports that the testing of seedlings since 1916 resulted in the selection of varieties of the Kothrud and Nasik types as best suited for general use, because of their vigor and hardiness. A selection called Lucknow 49 has been recommended for general planting. Since 1927 hybridization has been carried on to develop red-fruited varieties. Nine lots of seedlings representing different crosses are being tested out, but no selections have as yet been made for introduction. A variegated mutant has been propagated both for its fruit quality and for its ornamental value.

Feijoa

The feijoa (*Feijoa sellowiana* Berg), sometimes called the "green guava" because of its resemblance to the guava, is quite distinct from the latter. Its aroma is distinctly pleasant, and its flavor suggests the pineapple and the strawberry. It is fairly hardy, and a beginning has been made in its commercial planting in California. In Florida and the Gulf coast it is grown occasionally as a dooryard tree, both for its fruit and for its ornamental value.

Jaboticaba

The jaboticaba (*Myrciaria cauliflora* Berg), native to Brazil, is a member of the myrtle family. Preliminary tests of the tree in Florida have shown that it is fairly frost-resistant, withstanding 26° F. without severe injury. The small round fruits with pulp and skin somewhat like a large grape are remarkable in being borne on short stems directly on the trunk and larger branches of the tree, producing thick masses of glistening clusters all along the entire length of the branches. According to Popenoe (*87*), propagation is chiefly from seed, and named varieties have not as yet been developed. In southern Brazil it is as popular as the grape in the United States, the crop maturing in the warm months of the year.

Pomegranate

In the United States the culture of the pomegranate (*Punica granatum* L.), a native of Iraq, is chiefly confined to California (*38*). A collection of varieties was made by the Department, chiefly from the Mediterranean countries. The variety of chief importance commercially is one named Wonderful. It is of uncertain origin (*12*). The demand for this fruit is chiefly confined to those who have come from the Mediterranean region. The pulp consists of seed arils, and the large number of seeds is commonly considered objectionable. A variety in which the seed is tender and reduced to a vestigial rudiment would be a desirable objective in breeding.

B. Nazareth, at the College of Agriculture, Poona, India, reports that seedling selections of pomegranate of superior merit have been

made and recommended for general planting. Moringa and coworkers determined the haploid chromosome number in *Punica granatum* as 8 (table 5).

Jujube

The culture of the jujube (*Zizyphus jujuba* Mill.), or "Chinese date", has not reached commercial proportions in the United States. The fruits of the Chinese jujube most commonly grown resemble in size and shape an ordinary plump date, are dark brown in color, much firmer and drier than a date, and have a pointed oval seed or pit. They are borne on a small deciduous tree with spiny zigzag branches and slender leaves. As a food the fruit is chiefly valuable for the sugar content, which averages about 20 percent in the fresh fruit. The jujube is mainly of promise in the semiarid warm regions of the Southwest. Introductions by the Department, chiefly from China, where hundred of varieties are known to exist, have provided excellent material for selection and breeding (*121*). Scion collections of 68 selected varieties were secured by one explorer, Meyer, in 1908. Previous introductions had consisted chiefly of seeds, which gave unpromising results. The fruits of different varieties vary in size from that of a cherry to 2 inches or more in diameter. They are used chiefly for preserving, though the better varieties are relished by many in the fresh or dried form.

B. Nazareth, of the College of Agriculture, Poona, India, reports that a seedless jujube found occurring as a chance seedling has been propagated and distributed.

Lychee

The fruit of *Litchi chinensis* Sonn. may well be said to be the characteristic fruit of south China (*28*). Chinese poets and writers have sung its praises for centuries, the monograph of Ts'oi Seung in 1059 A. D. being the first of a long series of treatises on this unique fruit.

In western countries it is known chiefly in the dried form, which, because of its thin, brittle shell, is commonly called a "lychee nut." In this form it resembles a raisin sealed in a thin shell, but it has a flavor all its own. The fresh fruit is vastly superior to the dried form, besides having an esthetic appeal because of its crimson color. In size as well as color it resembles our cultivated strawberry. A tree bent over with these crimson fruits hanging in clusters is an unrivaled sight.

The lychee has not been seriously considered as a possible commercial fruit in the United States until recently, when scattered trees throughout Florida from early introductions have been found fruiting abundantly (fig. 16). Records of the Department from 1901 show a total of approximately 75 different introductions of the lychee into this country, from China, Java, India, and Hawaii. In Hawaii it has found a congenial home and a ready market among the large oriental population and is fast making a place for itself among the many fruits grown there.

One of the earliest and most successful introductions in Florida was that listed as P. I. 21204, secured in 1907 from Fukien Province by William N. Brewster, of Hinghua district. This variety is now known as the Brewster. Plants were distributed to cooperators in California and Florida, but the California climate has not proved well suited to lychee culture. Nursery propagation by the Chinese meth-

od, marcottage or air layering, was soon initiated in Florida, affording experimenters in the southern parts of the State opportunity to try out this new fruit. Little was known as to its cultural requirements, but notwithstanding many mistakes in handling, successful growth

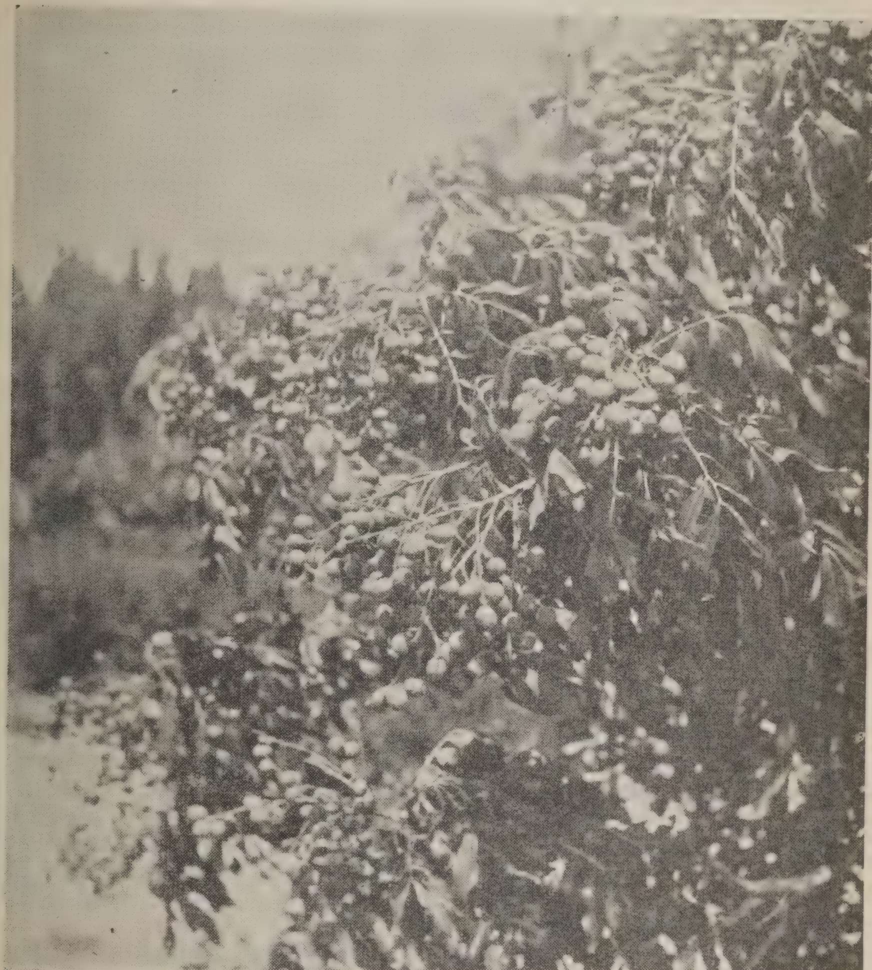

Figure 16.—Typical Florida-grown (Polk County) fruits of lychee of the Brewster variety, so called because of its having been secured and sent to the United States Department of Agriculture by William N. Brewster. This introduction was made in 1907 from the Hinghua district in the Fukien Province of south China. Connoisseurs familiar with the lychee rank this as one of the best of the lychees of China.

and good fruiting have been obtained in several locations. Noteworthy among the pioneers in lychee growing is E. L. Wirt, of Babson Park, Fla., who for over a decade has produced excellent crops of the Brewster lychee from a group of eight trees. Recently he has extended his plantings on a commercial scale, encouraged by the reception the fruit has met. While recognized as rather tender, the lychee has

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proved somewhat hardier than the mango. Its slow growth, especially during the first few years, has doubtless been a factor in the failure to recognize it earlier as a promising crop in Florida.

The lychee is subtropical rather than truly tropical. It grows well enough in tropical locations but does not fruit well where it is not checked by moderate winter chilling, as observed at Tela, Honduras.

Pollination does not appear to offer special difficulties, as observations indicate that a large majority of the flowers produced are perfect, with functioning anthers and pistils. There is erratic behavior, however, in some cases reported by Khan (*53*), which may call for further study. The fact that isolated trees have in several instances fruited heavily is evidence that in some varieties at least self-fertility is the rule.

Propagation has thus far been confined to marcottage or air layering of terminal branches, but experiments on the grafting of more vigorous seedling stocks are planned and successful unions have been secured. The rooting of leafy tip cuttings has been demonstrated as feasible with proper control of moisture and humidity. Recent introductions of the best Chinese varieties, such as the No Mai (nearly seedless), Sweet Cliff, Waachi, and others, together with seedling stocks of the Mountain lychee, should lead to greatly increased interest in this new fruit crop.

Variety collections of scion and stock varieties have been made at the Hawaii Agricultural Experimental Station (*31*) for testing and for various cultural studies. Physiological and anatomical studies are planned to overcome difficulties in the rapid propagation of these fruit trees.

Loquat

The loquat (*Eriobotrya japonica* (Thunb.) Lindl.) is one of the few representatives of the rose family the culture of which as a commercial fruit crop extends into the sub-Tropics. Probably a native of China, it has reached its highest development in Japan, where it is one of the important fruits of the country. While tolerant of a wide range of soil and climatic conditions, it is best adapted to relatively cool and dry subtropical areas such as southern California affords. In this area commercial groves have been developed within the last 20 years and the fruit is slowly growing in favor. Though it is often found as a dooryard tree in Florida and the Gulf coast sections, little or no commercial planting has as yet been undertaken.

The tree is semidwarf and is often planted as an ornamental. The yellow oval fruits are borne in clusters. They are subacid in most varieties, and the fruit may be eaten fresh like a plum or used in the cooked or preserved forms. The seeds, usually three to five or more in number, occupy considerable space in the pulp. A seedless variety would seem to be desirable in any breeding program.

As long as propagation was confined to seedling production the fruit attracted little attention, but with the introduction from the Orient of large-fruited varieties with superior flavor by the Department and private nurseries, the crop has gradually attained horticultural status. Seedling selections, notably those of Taft in California, have also led to the introduction of some excellent new varieties, such as the Champagne, Advance, Early Red, and Victor. These,

with the Tanaka, Premier, and Thales (a sweet variety), constitute most of the present-day plantings. Propagation is by budding or grafting, seedling loquats serving best as stocks, although the quince is sometimes used where a dwarf tree is desired.

Taiji Miki, professor of pomology at the Chiba Horticultural College in Japan, is studying cold resistance in loquat varieties. The chief varieties now grown are Kusunoki, early, and Tanaka and Mogi, late.

R. D. Fordham, deputy director of gardens, United Provinces, Saharanpur, India, reports that two outstanding loquat varieties have been secured by mass selection. These are Fordham Best—fruits very large, conical shaped, juicy and sweet and of a rich red color; and Delicious—fruits very large, oblong, juicy white flesh, fruit borne in bunches.

T. Tanikawa, acting director at the Imperial Horticultural Experiment Station, Okitsu, Japan, reports that since 1916 about 5,000 hybrid progeny have been secured from crosses between five different varieties, and that more than 10 promising selections have been made.

White Sapote

The white sapote is a native of the highlands of Mexico and Central America, where it is an important product. The name sapote is used in the Tropics to designate quite a number of fruits differing widely both horticulturally and botanically. The white sapote (*Casimiroa edulis* Llave and Lex.) does not belong in the Sapotaceae but is a rutaceous plant and as such is about as hardy as the orange, belonging to the same family. Structurally, however, the fruit is more like a rounded pear, with soft, very sweet pulp, sometimes tinged with a bitter flavor. The color is yellowish green and the fruit has a thin membranous skin. Seeds are few but large and smooth. The tree is easily grown from seed and is beginning to receive some attention in both California and Florida. It can be readily propagated by budding and grafting, and several selections have been made for nursery propagation and distribution. Among the named varieties are the Johnson in Florida and the Wilson in California. No experiments have yet been made to determine shipping and keeping quality. As it becomes better known the fruit will probably be grown largely to meet local demands.

Cherimoya

Most of the species of *Annona* are too tender for commercial production in the United States, but the cherimoya (*Annona cherimola* Mill.) is semihardy, being a native of the highlands of South America and naturalized at elevations of 3,000 to 6,000 feet in Mexico. It attains its best character, as pointed out by Popenoe (*90*), in regions characterized by dry, cool climates and has proved at home in portions of coastal California. While not well adapted to more humid regions, such as Florida, hybrids with the more tropical species, such as the sugar-apple, have been reported by Wester (*135*) and may pave the way for developing fruitful varieties for such locations. The fruit is usually heart-shaped, the numerous carpels fusing to form a fleshy receptacle the size of an orange or larger. The flesh is white, melting in texture, with subacid flavor suggesting the pineapple and the banana.

While propagation is usually from the rather numerous brown seeds, a beginning has been made in California in selecting and budding from superior seedlings to establish the fruit on a secure horticultural basis.

B. Nazareth, of the College of Agriculture, Poona, India, reports that among the subtropical fruits of lesser importance breeding work has been carried on since 1917 with the annonas. Hybrids have been secured between *Annona cherimola* and *A. squamosa* L., but have not yet been introduced into cultivation.

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APPENDIX

TABLE 5.—*Chromosome numbers of subtropical and tropical fruit species and varieties other than Rutaceae as far as determined up to 1936*

[See literature citations (*10; 13; 14; 20; 27; 31; 32; 33; 49; 73; 81; 122, pp. 109–226*)]

Family and species	Chromosome number		Authority and year determined	Remarks
	n	*2n*		
Moraceae:				
Ficus carica	13		Condit, 1928	
F. glomerata		[1] 24	do	
F. altissima	13		Kraus, 1930	
F. elastica	+13		Condit, 1928, Kraus, 1930	
F. erecta	+13		Condit, 1928	
F. palmata (=*pseudocarica*)	13		do	
F. panduraefolia	[1] 13		Kraus, 1930	
F. pandurata	+13		do	
F. parcelli	+13		do	

[1] Probably.

TABLE 5.—*Chromosome numbers of subtropical and tropical fruit species and varieties other than Rutaceae as far as determined up to 1936*—Continued

Family and species	Chromosome number		Authority and year determined	Remarks
	n	*2n*		
Moraceae—Continued.				
F. rubiginosa	+13		Condit, 1928	
F. schlechteri	[1] 13		Kraus, 1930	
F. sycomorus	[1] 13		do	
F. triangularis	[1] 13		do	
F. benghalensis	[1] 13		do	
F. quercifolia	+14		do	
F. repens	[1] +14		do	
F. roxburghii				Undetermined.
Lauraceae:				
Persea americana		[1] 24	Van Elden, 1927–28	
	12		Longley, 1932	Determinations of 11 varieties including West Indian, Guatemalan, and Mexican races.
Caricaceae:				
Carica papaya	9		Heilborn, 1921 Meurman, 1925 Sugiura, 1927 Asana and Sutaria, 1929 Lindsay, 1930	
C. candamarcensis	9		Heilborn, 1921	
C. chrysopetala	9		do	
C. pentagona	9		do	
Passifloraceae:				
Passiflora princeps var. *coccinea*		18	Heitz, 1926	
P. caerulea		18	do	
P. alba	9	18	Storey, 1936	
P. edulis		18	do	
P. edulis forma *flavicarpa*	9	18	do	
P. foetida	10	20	do	
P. foetida var. *gossypifolia*	10		do	
P. laurifolia	9	18	do	
P. ligularis		18	do	
P. maliformis		18	do	
P. pfordtii		18	do	
P. seemanni	9	18	do	
P. suberosa	12	24	do	
P. vitifolia	9	18	do	
Punicaceae:				
Punica granatum	8		Moringa et al., 1929	
Guttifereae:				
Garcinia treubii	±24	±48	Treub, 1911	
Rhamnaceae:				
Zizyphus vulgaris var. *inermis*.	12		Moringa et al., 1929	
Ebenaceae:				
Diospyros kaki	(27)–28		Yasui, 1916	Horticultural varieties Tenryubo, Jenijmam, Tanonashi, Fuyu.
Do	45		Namikawa and Higashi, 1928	Horticultural varieties E-Gosho, Kurokama, Nara-Gosho, Shogatsu.
Do	45	90	Higashi, 1928	Seedling of Kubo.
Do		90	do	Seedlings of Anzai and Tenjin-Gosho.
D. lotus	15	30	do	
D. virginiana	[2] 30		Hague, 1911	
Bromeliaceae:				
Ananas sativus	25		Collins and Kerns, 1931	Smooth Cayenne, Queen, Ruby, Pernambuco, Spiny Guatemala.
		75	Heilborn, 1922	Clone from South America.
		75	Collins, 1931	Cabezona variety.
Palmaceae:				
Phoenix dactylifera		28	Nemec, 1910	
P. farinifera	18		Narayana, 1936	

[1] Probably. [2] At least.